SCHOOL OF CIVIL ENGINEERING

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JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-84-4

INDIANA HIGHWAY COST-ALLOCATION STUDY: A REPORT ON METHODOLOGY

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Interim Report

INDIANA HIGHWAY COST ALLOCATION STUDY:
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To: H.L. Michael, Director
Joint Highway Research Project

From: K.C. Sinha, Research Engineer
Joint Highway Research Project

March 14, 1984

Revised: October 10, 1984

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Attached is the Interim Report on the HPR Part I Study titled, "Indiana Highway Cost Allocation Study." This report presents the methodology to be followed in the cost allocation study for Indiana and it has been prepared under the direction of Professor K. C. Sinha.

The proposed methodology conforms to the mandate of the H.E.A. 1006 of the 103rd General Assembly and it is also consistent with the Federal cost allocation study approach.

This report is forwarded for review, comment and acceptance by the IDOH and FHWA as partial fulfillment of the objectives of the study.

Respectfully submitted,

K.C. Sinha

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16. Abstract

This interim report presents the proposed methodology for the cost-allocation study in Indiana. It describes the highway classification, vehicle classification, cost categories and expenditure items, revenue categories and guiding principles for appropriately assigning the expenditure and revenue among the various highway users. A thickness incremental approach is proposed to allocate new highway construction cost and an integrated approach is proposed to allocate highway rehabilitation and routine maintenance costs. The incremental procedure to allocate structure construction and rehabilitation costs is also presented. In addition, the report provides a detailed discussion of the traffic data collection procedure used in the study.

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Interim Report

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in cooperation with the

Indiana Department of Highways

and the

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INTRODUCTION

The Indiana highway system consists of 11,294 miles of State Roads, 66,564 miles of County Roads and 13,818 miles of City Streets. The Federal-Aid portion of the Indiana highway system is comprised of 1144 miles of Interstates, 5064 miles of Primary, 8980 miles of Secondary and 4828 miles of Federal-Aid Urban highways. For all governmental units combined, annual expenditures for highway purposes in Indiana are well over 3/4 billion dollars.

As a part of the House Enrolled Act 1006, the 103rd Indiana General Assembly required the Indiana Department of Highways (IDOH) "to undertake a highway cost-allocation study to (a) document the full cost of building and maintaining the state's highway system, including that portion of the Federal Interstate system within Indiana; and (b) develop an equitable methodology for allocating such costs to all the users of the system".

This study, entitled Indiana Highway Cost-Allocation Study, was initiated by the Advisory Board of the Joint Highway Project of Purdue University in cooperation with the IDOH on May 4, 1983. It is being carried out in two phases. The major tasks undertaken in Phase I are literature review, study design, data collection and data analysis. Those included in Phase II are development of the methodological framework, preparation of an interim report, determination of travel functions and current cost responsibility, sensitivity analysis, future cost responsibility and preparation of a final report.

This interim report is one of the tasks in Phase II. It examines the methodology and procedures adopted by previous studies of other states to determine cost responsibilities of various highway user groups. A procedure

for use in Indiana is proposed and discussed in sections of this report.

Purpose of the Study

The main objective of this study is to fulfill the requirement of the legislative directive mentioned earlier by determining the responsibility of individual vehicle classes in occasioning highway costs. The total highway costs and traffic distribution must first be determined in the highway system concerned. Subsequently, an equitable cost-allocation procedure is to be devised to derive the cost responsibilities of various vehicle classes.

Although determination of the revenue contributed by each vehicle class is not within the initial scope of the present cost-allocation study, the study would not be complete without such information. The results of the cost-allocation study would be meaningful only if it is compared to the user revenue contribution. It is therefore decided to include determination of revenue contribution of individual highway user classes as a task in the Phase II of this study. The revenue contribution of each user class could then be compared with its cost responsibility. This comparison would enable one to determine if the contribution of each user class matches its cost responsibility for the highway costs.

Highway Classification

The House Enrolled Act 1006 indicated that the highways to be considered in the cost-allocation study include the State's highway system, including that portion of the Federal Interstate system within Indiana. Following this directive, all public roads in Indiana are considered in this study. Toll roads, however, are not included. Exclusion of toll roads is justified

because the construction and maintenance of these roads are paid directly by the toll road users and are not part of the state highway expenditures.

In the process of determining the type of highway classification to be used, the merits of different types of highway classifications were examined. A review was made of the classifications adopted in several other cost-allocation studies, as summarized in Table 1.

The main concern is to select a classification which would lead to an accurate allocation of highway cost. Two important criteria are (i) the data availability by type, and (ii) the accuracy of the cost-allocation figures. Often traffic data are available according to functional classification, while cost data are given in terms of jurisdictional classification. A classification must be sought such that matching and transferring of the two sets of data would not introduce unnecessary inaccuracy in the study results.

The most logical set of criteria for highway classification appears to be:

a. a classification which best satisfies the needs of cost allocation;

b. a classification which covers all the road systems specified in the scope of the present study; and

c. a classification which is compatible to the available data from the IDOH and other highway agencies in Indiana.

Following these criteria, the following highway classification was adopted:

Table 1. Highway Classifications Used in Other Cost-Allocation Studies.

Study	Highway Classification
Georgia (1978)	1. Interstate - Rural 2. Interstate - Urban 3. Other Federal Aid Primary - Rural 4. Other Federal Aid Primary - Urban 5. Federal Aid Secondary - Rural 6. Federal Aid - Urban 7. Other State - Rural 8. Other State - Urban
Kentucky (1982)	1. Interstate - Rural - Urban 2. Federal Aid Primary - Rural - Urban 3. Federal Aid - Urban 4. Federal Aid Secondary - Rural 5. Non Federal Aid State Maintained - Rural - Urban
Maryland (1983)	1. State Highway System a. Interstate - Urban - Rural b. Primary - Urban - Rural c. Secondary - Urban - Rural 2. County Roads 3. Municipal Streets
North Carolina (1983)	1. Interstate 2. Arterial - Rural - Urban 3. Collector - Rural - Urban 4. Local - Rural - Urban
Oregon (1980)	1. Interstate - Rural 2. Interstate - Urban 3. Primary - Rural 4. Primary - Urban 5. Secondary - Rural 6. Federal Aid - Urban 7. County Roads 8. City Streets

Table 1. (Continued)

Study	Highway Classification
Wisconsin (1983)	1. Rural Interstate 2. Urban Interstate 3. Rural State Trunk 4. Urban State Trunk 5. County Trunk 6. Town Roads 7. City & Village Streets 8. Other Roads
Wyoming (1981)	A. Rural 1. Interstate 2. Other Primary Arterial 3. Minor Arterial 4. Major Collector 5. Local Roads B. Urban 1. Interstate 2. Freeways 3. Other Principal Arterial 4. Minor Arterial 5. Collector 6. Local Streets

1. Interstate Urban

2. Interstate Rural

3. State Routes Primary

4. State Routes Secondary

5. County Roads

6. City Streets

The adopted highway classification conforms well to the functional classification used by the FHWA in recording HPMS data. At the same time, this classification allows identification of the highway system by jurisdiction.

Vehicle Classification

The basic idea of vehicle classification is to group vehicles having similar characteristics with respect to highway use and highway damage. Ideally, each group must be small enough so that the cost responsibility calculated would represent accurately the cost responsibility of the individual user within the group. On the other hand, the number of groups cannot be so large as to make data sets too formidable to handle. The classification used must reflect the range of highway users in Indiana. It also must be such that the existing data at the IDOH can be used and any new data collected can in turn be employed by the IDOH for other purposes.

Most classification systems used in cost-allocation study follow a two-step procedure: (i) major classes according to function type of vehicles, e.g., passenger cars, buses and trucks; (ii) subdivision of these major

classes into smaller grouping based on vehicle weights and/or axle configuration.

Both the 1982 Wisconsin study [36] and 1980 Oregon study [26] used 2000-lb divisions to allow maximum flexibility in fitting vehicle groupings to different allocation processes; whereas the 1983 Maryland study [32] subdivided truck weights into 4000-lb increments. Another approach adopted by the 1982 Maine study [21] and the 1982 Kentucky study [4] identified sub-groupings of functional classes in terms of axle configuration. Table 2 presents a summary of vehicle classification system used in cost-allocation studies by several other states.

A point to note regarding the weight classification is that different types of weights have been used for this purpose. For instance, the 1983 Maryland study [32] used gross registered weight, the 1982 Wisconsin study [36] and 1980 Oregon study [26] used gross operating weight, and the 1981 Wyoming study [33] used empty vehicle weight. Use of gross registered weight facilitates computation of revenue contribution, but transformation to operating weight is needed for assessing cost responsibilities. The reverse is true of classification using gross operating weight.

In the present study vehicles will be classified according to vehicle type and gross operating weight. For the purpose of aggregating cost-responsibility and revenue attribution figures, vehicle types can be grouped in a number of relevant categories, as shown below:

Group I: All passenger cars, motor cycles, pickup/panel trucks, and other 2-axle, 4-tired trucks;

Group II: 2-axle, 6-tired trucks and buses and other single unit trucks and buses with 3 or 4 axles;

Table 2. Vehicle Classifications in Other Cost- Allocation Studies

Study	Vehicle Classification
Georgia (1978)	1. Cars 2. Pickups, Panels & Other 2 axle Single Tire Trucks 3. 2 or 3 axle Single Unit Trucks with dual Rear Tires 4. Buses 5. Tractor truck Semi-Trailer - 3-axle, 4-axle, 5-axle
Kentucky (1982)	1. Standard & Compact Autos 2. Subcompact Autos 3. Pickups 4. Buses 5. Trucks: SU-2A-4T, SU-2A-6T, SU-3A, C3A, C4A, C5A, C6A, C7A, C8A
Maine (1982)	1. Basic Vehicle - passenger cars, pickup/panel trucks, other 2-axle 4-tired trucks 2. Single Unit Truck - 2-axle, 6-tired 3-axle 4-axle 3. Combinations - 3-axle 4-axle 5-axle 6-axle
Maryland (1983)	1. Automobiles 2. Buses 3. Pickups/Vans 4. Single Unit trucks (Class E) 5. Dump Truck 6. Truck Tractors (Class F)
North Carolina (1983)	1. Autos & light trucks - autos, motorcycles, pickups, vans and other 4-tire trucks 2. Single unit truck of 2 or 3 axles with 6 or more tires 3. Combination trucks - includes all 3, 4, and 5 axle tractor-trailer combinations.
Oregon (1980)	1. Basic Vehicles - 0-2000, 2001-4000, 4001-6000 (lb. o[illegible] registered wt.) 2. Heavy Vehicles - 6001-8000, 8001-10,000, 98,001-100,[illegible] (lb. of registered wt.)

Table 2. (Continued)

Study	Vehicle Classification
Wisconsin (1982)	Vehicles are classified into divisions according to gross operating weight with 2000 lb. increments, from 0-2 kip up to 80 k and above. Different groupings of these 2000 lb. divisions are used for allocating different expenditure items.
Virginia (1982)	Class I - All passenger cars, pickup trucks, panel trucks and motorcycles. Class II - All 2-axle, 6-tire trucks and buses Class III - All 3-axle, single-unit trucks & buses Class IV - Combinations, 3-, 4-, & 5-axle tractor-trailers.

Group III: Combinations, 3 or more axles.

Based on traffic count data, vehicles have been grouped into fourteen classes as defined in Table 3. Data from trucks weighing stations will be used to subdivide nine of the fourteen classes in terms of gross operating weights. The nine classes are Class 3, 6, 7, 9, 10, 11, 12, 13 and 14. For these nine classes, all cost-allocation analyses will be carried out in weight divisions of 2500 pounds.

Costs to be Allocated

Most cost-allocation studies have chosen to use actual expenditure instead of needed expenditure as the allocated costs. The primary reason for not using needed expenditure is that there are no fixed criteria as to what level of highway needs have to be satisfied. Rather than making more assumptions in order to derive a needed expenditure, the actual expenditure is used because it represents the amount spent in a given year and can be directly related to the revenue contribution of the same year.

The HEA 1006 requires that the study consider the full cost of building and maintaining the state's highway system. Full costs are really what we have been spending and an estimate of these estimates can be made by examining actual expenditures for a period of time. Actual expenditure may change from year to year. This change may be brought about by changes in area of emphasis in expenditure program or availability of fund. However, if actual expenditures for a number of years are considered, a great part of the yearly variation can be discounted.

The definition of "full costs" used in the study is valid as confirmed by

Table 3. Adopted Vehicle Classification.

Class	Description
1	small passenger cars
2	standard and compact passenger cars, panel and pickup
3	2-axle truck (2S and 2D)
4	bus
5	car with 1-axle trailer
6	3-axle single unit truck
7	2S1 tractor-trailer
8	car with 2-axle trailer
9	4-axle single unit truck
10	3S1 tractor-trailer
11	2S2 tractor-trailer
12	3S2 tractor-trailer
13	other 5-axle
14	6 or more axle

other state studies. Although "full costs" in one sense of meaning might be defined as what should have been spent to maintain the highway system at a "reasonable level," the fact remains that disagreement with users as to the "reasonable level" will result and determination of that cost will also be subject to question. On the other hand, what was spent is fact and was what the users provided.

The fact that actual expenditures are used in most cost-allocation studies explains why such a study has to be carried out from time to time to check that each user group is paying its fair share of responsibility.

In cost-allocation study, expenditure is commonly divided into distinct categories such as construction, rehabilitation and maintenance. As shown in Table 4, there is only minor difference in the main expenditure categories defined in the cost-allocation studies carried out by other states. The present study follows the general categories used in the State cost data. The exact categories are as follows:

Highway Construction

Highway Rehabilitation

Structure Construction

Structure Rehabilitation

Maintenance and Operation

Other Costs

Each expenditure category is further subdivided into a number of expenditure items. These subdivisions enable more accurate cost-allocation to be carried out. This is mainly because each expenditure item is likely to have different responsible attributes (or cost-allocators). The detailed division

Table 4. Expenditure Categories in Other Cost-Allocation Studies

Study	Main Expenditure Categories
Georgia (1978)	1. Construction - ROW, grading & drainage, pavement, bridges 2. Maintenance - Surface, shoulder, resurfacing, all other maintenance
Kentucky (1982)	A. Capital Expenditures 1. Preliminary design & engineering 2. ROW 3. Utilities 4. Grades & Drain 5. Pavement 6. Bridges B. Annual Maintenance & Administrative Expenditures 1. Maintenance of state system 2. Administration of state system 3. Maintenance & Administration of local roads & streets 4. Law enforcement & safety 5. Mass transportation
Maine (1982)	1. Maintenance & Operations - vehicle related, traffic related, bridge superstructure, traffic remote 2. Highway Construction - min. roadway, extra strength, extra width 3. Bridge Construction - approaches, obsolescence, min. bridge, extra strength, extra width 4. Local Assistance Program 5. Other
Maryland (1983)	1. Construction - ROW, Grading & Drainage, pavement, shoulder, bridge superstructure, bridge substructure, others 2. Special projects - beautification, safety, bridge replacement/rehabilitation, traffic control, emergency 3. Maintenance - roadway shoulders, roadside & drainage, winter maintenance, traffic service, structures, overload, maintenance support services, non-routine maintenance 4. Administration

Table 4. (Continued)

Study	Main Expenditure Categories
North Carolina (1983)	1. Construction - new location, widening, reconstructic resurfacing, bridge replacement 2. Maintenance - pavement repair, non-pavement repair 3. Secondary Road Costs
Oregon (1980)	A. Construction: 1. Preliminary engineering 2. ROW 3. Grading, drainage, miscellaneous structure 4. Surfacing 7. Roadside improveme 5. Overlays 8. Traffic Services 6. Structures 9. Construction engineering B. Maintenance: 1. Surface, flexible 7. Roadside 2. Surface, rigid 8. Pavement marking & stripir 3. Shoulders 9. Traffic Control facilities 4. Guardrails & fence 10. Sanding 5. Structures 11. Snow, ice & other 6. Drainage 12. Extraordinary maintenance
Virginia (1982)	1. Roadway construction - size preparation, pavement, F & construction engineering 2. Bridge construction & reconstruction 3. Maintenance Costs - pavement repair & replacement, shoulder, special purpose facilities, other maintenance 4. Other Costs
Wisconsin (1982)	1. Highway Construction - ROW, earthwork, culverts, roadway, pavement, Shoulder, signing, miscellaneou 2. Structure Construction - bridges, box culverts, sigr bridges 3. Highway Rehabilitation - earthwork, culverts, roadwa areas, pavement, shoulder, safety items, etc. 4. Structure Replacement 5. Maintenance - roadside, wayside & rest area, snow & ice removal, pavement, shoulder & bridge, traffic services 6. Special Vehicle Services - enforcement (policing), weight inspection, administration

of each expenditure category into smaller items depends largely upon the degree of breakdown available in the cost data. The expenditure items listed in Table 5 were adopted after careful examination of the cost data files.

Time Frame of Study

The base period cost analysis is being carried out for four years, 1980 to 1983. Traffic and cost data are being analyzed for the base period to determine the appropriate allocation factors, while the study period analysis is for the comparison of cost responsibility with revenue responsibility. The allocation factors from base period will be applied to the study period (1985-86) budgeted expenditure to arrive at the cost responsibility of each vehicle class for the study period. These cost responsibility figures will then be compared to the appropriate revenue contribution figures.

The basic assumption involved in this procedure is that the cost responsibility factors in the study period would remain the same as those calculated for the base period. This assumption is reasonable because the types of vehicles, types of facilities and the technology as a whole would not change significantly over a short period - about five years in the present study.

Table 5. Expenditure Items by Expenditure Area

Highway Construction	Structure Construction and Replacement	Highway Rehabilitation	Structure Rehabilitation	Routine Maintenance	Other Costs
Right-of-Way	Excavation and Backfill	Grading and Earthwork	Concrete	Drainage and Erosion Control	Enforcement (policing)
Grading and Earthwork	Concrete	Drainage and Erosion Control	Steel Rein-forcements	Pavement and Shoulder	Weight Inspection
Drainage and Erosion Control	Steel Rein-forcements	Pavement and Shoulder	Structural Steel	Bridge	Special Railroad Crossings
Pavement	Structural Steel	Miscellaneous Items	Miscellaneous Items	Miscellaneous Items	
Shoulder	Piers and Piling				
Miscellaneous Items	Culverts and Sign Structures				
	Miscellaneous Items				

COST-ALLOCATION METHODOLOGY

Guiding Principles

There are two broad approaches to highway cost-allocation studies, namely the equity approach and the efficiency approach. Ideally, highway cost-allocation study should result in an equitable and efficient highway user financing system so that each user group would be paying its fair share of cost responsibility in terms of revenue contribution.

To be fully efficient, economic theory requires that the price of a trip be equal to the extra or marginal costs caused by that trip. Under this approach, highway users during peak hours would be charged at a higher rate than other users who use highways during off-peak periods. Similarly, highway users in heavily developed area have to pay higher charges than other users in less congested areas. Understandably, much more detailed information than ordinarily available traffic and transportation data is required before such a study can be carried out. There are other difficulties in following this approach even if all the required data were available. Firstly, it cannot be applied directly in a highway cost-allocation analysis because it is extremely difficult to relate marginal costs to levels of expenditures. Most importantly, user charge instruments cannot be easily developed and implemented that vary geographically and by time of day - a requirement for efficient pricing. As a result, the efficiency has not been adopted as the main criterion in other cost-allocation studies although the approach has a sound economic concept of market pricing.

Virtually all cost-allocation studies follow the equity approach. Equity itself is a subjective concept and a clear definition is needed for

application. Equity can be judged by one of the following three criteria [35]:

a. Costs should be assigned to users in proportion to the benefits they receive.

b. Costs should be assigned to users in proportion to the costs they cause (occasion).

c. Costs should be assigned to users in proportion to their ability to pay.

The definition of equity appropriate for highway cost-allocation studies is that related to cost-responsibility or the cost occasioned by various vehicle groups. The present cost-allocation study, based on the equity approach, aims to develop a procedure which is both practical and theoretically sound.

<u>Overview of the Study Approach</u>

The major steps in the present cost-allocation study are identified in this section, and these are:

a. Collection of data: Data collected consist of three sets. The first set involves highway traffic data, the second set consists of highway cost data and the third set deals with highway revenue data.

b. Establishing Input Data: Two approaches are being pursued to develop the necessary cost and traffic input data to the cost-allocation analysis. In previous cost-allocation studies traffic data were collected on a sample basis from various highway sections and aggregated before combining with the total cost data to determine allocation factors. While this procedure is valid,

there can be another approach where both cost and traffic data are identified for specific randomly selected sections and the cost-allocation factors are developed on the basis of this sample. It can be argued that such "vertical" sampling approach would avoid the possible bias of aggregating traffic data before combining with the cost data. However, the vertical sampling approach would require a very large sample size. In the present study, effort will be made to evaluate the merits and drawbacks of each of the two sampling approaches.

c. Identifying Attributable and Non-attributable Costs: One of the major issues in cost-allocation study is to determine the proportions of attributable and non-attributable costs in each expenditure item. Attributable costs are costs which can be attributed to specific vehicle classes, whereas non-attributable costs are those which are not related to vehicular characteristics and vehicle use. Non-attributable costs can therefore be considered as common costs to all highway users.

d. Selection of Cost-Allocators for Expenditure Items: After identifying attributable and non-attributable costs, the next step is to select suitable cost-allocators to distribute these costs among vehicle classes. Due to the differing nature and causes of various expenditure items, it is not possible to use a single cost-allocator that is satisfactory for all expenditure items. In order to distribute equitably highway costs among vehicle classes in proportion to their responsibility for occasioning these costs, an appropriate cost-allocator must be selected for each expenditure item so as to reflect as closely as possible the relationships between particular expenditure items and the specific vehicle classes. A separate set of allocators also needs to be selected for distributing the non-attributable or common costs among user

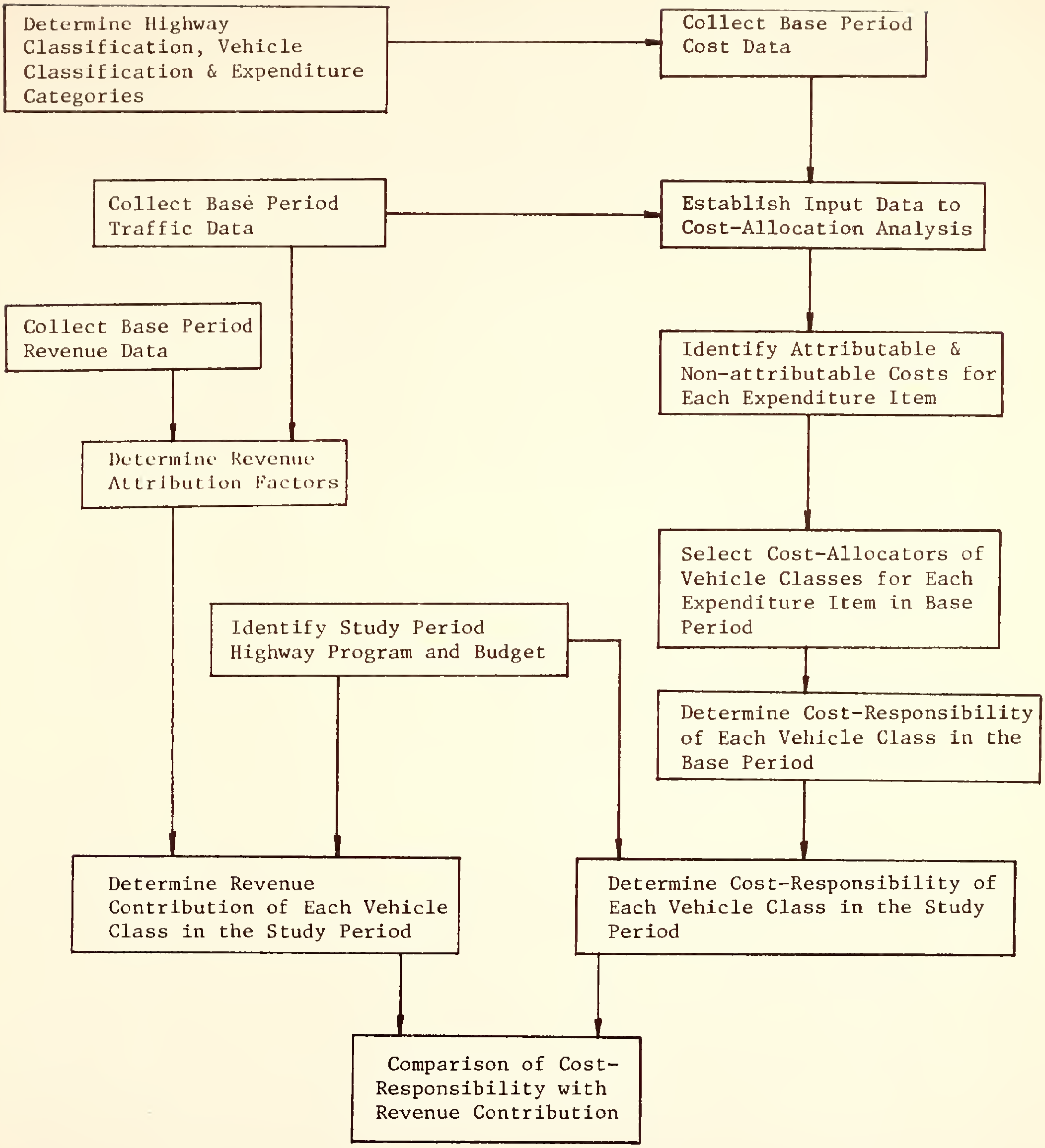
groups.

e. Determination of Cost-Responsibility Factors: The direct consequence of using different expenditure items is obvious - the proportion of cost responsibility (i.e. the cost responsibility factor) of a specific vehicle class for different expenditure items would be different. As mentioned earlier, cost-responsibility factors are determined using the base period data. These factors are then applied to the study period budgeted expenditure to arrive at the cost-responsibility for each vehicle class in the study period.

f. Determination of Revenue Attribution: Once the cost-responsibilities are determined, it is necessary to compare them with the revenues contributed by each vehicle class. This will be accomplished by examining the separate sources of revenues paid by Indiana highway users and then apportioning the revenue amounts by vehicle class.

A flow chart is shown in Figure 1 to summarize the discussion presented in this section. Such items as highway classification, vehicle classification and expenditure categories must be determined before cost-allocation analysis can proceed.

Figure 1. Cost-Allocation Study Flow Chart



DATA NEEDS

Traffic Data

A detailed traffic count data for the state highway system are available in the IDOH. However, the available truck classification and weight data were collected not on the basis of random statistical sampling to represent the highway classes in the state. Consequently, a comprehensive vehicle classification survey has been undertaken by the study group. In order to make the collected truck data usable for other purposes by the IDOH, the highway classes and vehicle classes were made to match the FHWA and IDOH truck weight study requirements.

The vehicle classification survey included a series of 24-hour manual vehicle counts and a series of 24-hour machine vehicle counts on statistically sampled sections of highways during the summer of 1983. A detailed discussion of the traffic data is presented in a later section of this report.

The truck weight data for several years from weigh stations are available through the Planning Division of the IDOH. These loadometer data provide operating weight, registered weight, vehicle type, number of axles and their configurations.

Cost Data

Cost data are being collected separately for the state highway system and for the local roads.

State Highway System

The cost and highway physical inventory is being compiled for the state

system on the basis of the following data sources:

1. Road Life Records - The information is based on actual contracts, and it provides a detailed description of pavement characteristics. The data from all of the 874 sections have been extracted manually from the IDOH records and coded and entered in computer. Although this source provides a detailed description of the various highway activities performed on the state highway system, cost information is often not complete. When available, the cost items are given as follows: Grading and Drainage, Subgrade, Surface and Base, Bridges, Traffic Service, Landscape, and Engineering Inspection.

2. Construction Reports - These reports, prepared periodically by the Construction Division of the IDOH, provide cost information (total cost) for any contract or a group of contracts in a given time period. These data are already computer coded and will be of use when the Road Life Records do not contain enough cost information.

3. Itemized Cost Estimates - For any contract, a cost estimate proposal is prepared by the IDOH Construction Division. These itemized estimates can be used to obtain the distribution of contract costs for different expenditure items (earthwork, culverts, pavement, shoulder, etc.). These data are already computer coded.

4. Routine Maintenance Records - The IDOH Maintenance Division prepares crew day cards files to keep records of all routine maintenance activities done in a given year. Data for the last four years have been obtained

and information on type of maintenance, location, production units, man-hours, material types and quantities are currently being analyzed by the study team.

In addition to the above sources, expenditure data reported by the IDOH on the PR-534 and on HPMS sections will also be analyzed.

Local Roads

1. Road Inventory - An inventory of physical characteristics of the local highway system in Indiana is available at the Planning Division. It should be noted, however, that the available data need extensive updating.

2. County and Municipal Highway Expenditure Data - From the Annual Reports, data on total receipts and disbursements by fund category for each county have been extracted. Similar information has been gathered for municipalities. The major categories of expenditures include administrative costs, maintenance and repair, and construction and reconstruction.

3. Personal Interviews - Personal contacts are being made with a group of county and city highway agencies to receive detailed cost data that can be used to distribute the aggregated data collected from the Annual Reports. Pavement type and other related information is also being collected through direct contact with the local highway agencies.

<u>Revenue Data</u>

Highway revenues in Indiana primarily consist of user taxes and fees,

including motor fuel taxes and special fuel taxes, vehicle registration fees, motor carrier fees and vehicle operator's fees. There are some other revenues in the form of fines and charges. The highway revenues also include intergovernmental transfer of funds from federal to state and local governments and from state to local governments.

Revenue data for the base period are being collected from appropriate agencies including Indiana Department of Highways, Indiana Department of Revenue, Bureau of Motor Vehicles and Public Service Commission. The information on highway revenues at local levels is being collected from Annual Reports and personal interviews. The local level data need to be further identified by source, because only that part of the local highway cost supported by highway user revenues should be considered in cost-allocation analysis.

<u>Traffic and Cost Input Data</u>

A typical way of setting up the cost input data is illustrated by the procedure explained in the Wisconsin study [36]. Cost data for the base period are obtained from expenditure records. These data are first distributed among highway categories. Within each highway category, expenditures are distributed among major expenditure areas. Lastly, expenditure for each of the major expenditure areas is distributed among specific expenditure items.

As with most other studies, the primary source of information for traffic and road use is data from actual field observation for the base period. Road use and vehicle classification information for each highway category are esta-

blished from these data. The distribution of vehicle-miles of travel by weight class of each of the vehicle groups will be accomplished primarily through the IDOH truck weight study information. The VMT figures generated will be cross-checked with the information from the Highway Performance Monitoring System.

Attributable and Non-Attributable Costs

Proportions of attributable and non-attributable costs cannot be easily defined for most expenditure items. One of the principal causes which give rise to this problem is the fact that damages of highway elements are usually the result of interaction of several factors, and there is no theoretical solution which could enable one to identify specifically the appropriate proportion of each factor. Two major factors responsible for damages of pavement and structure are traffic and environment, and other possible factors may be poor construction, poor engineering design and substandard construction materials.

In view of the complexity of the problem, it is not surprising to find that most cost-allocation studies have used different definitions for the cost components of expenditure items. A summary of definitions adopted by different studies is presented in Table 6.

In general, it may be said that most researchers agree on the need to single out common cost (or residual cost or fixed portion cost) which cannot be directly attributed to any user class or group of user classes. However, there is no agreement as to how the proportion of this common cost should be computed for each expenditure item. Almost without exception, most studies

Table 6. Definitions of Expenditure Cost Components

Study	Cost Components
Wisconsin (1983)	1. Basic Portion - to provide a level-of-service for the smallest reasonable number of vehicles of the the smallest reasonable size or weight 2. Service Portion - to provide a level-of-service beyond the basic level 3. Fixed Portion - cost not related to vehicle weight, size or use
Maryland (1982)	1. Base Facility Costs - to provide service assuming all vehicles are composed of char. similar to the basic vehicle, the automobile 2. Occasioned Costs - (a) weight occasioned (b) size (width) occasioned (c) trucks only (d) automobiles only
Oregon (1980)	1. Weight-related Costs 2. Non-Weight-related Costs - (a) costs assignable to all vehicles (common costs) (b) costs assignable to basic vehicles only (c) cost assignable to heavy vehicles only
North Carolina (1983)	1. Attributable Costs - costs attributable to vehicle type 2. Common Costs - costs that individual vehicle share irrespective of the size and weight of the vehicle
Virginia (1982)	1. Occasioned Cost - (a) traffic occasioned cost (b) demand occasioned cost 2. Common Cost
Iowa (1983)	1. Uniquely Occasioned Costs - cost entirely attributable to unique classes of users 2. Jointly Occasioned Costs - costs which are attributable directly to users but for which some allocation procedure must be used to assign specific cost responsibility to user classes 3. Residual or Common Costs - cost cannot be attributed to any particular class of highway user
Maine (1982)	1. Costs related to a specific vehicle class 2. Costs related to traffic as a whole 3. Costs not related to traffic effects 4. Special expenditure made on bridges

Table 6. (Cont'd)

Study	Cost Components
FHWA (1982)	Attributable Costs - costs which are attributed to each vehicle class based on particular vehicle char. felt to bring about or occasion the costs Common Costs (residual costs) - costs allocated among all vehicle classes on the basis of some equitable criterion.

selected a value based on judgment or a survey of expert opinions.

Estimation and Allocation of Non-Attributable Costs

As mentioned in the preceding section, there is considerable controversy on the magnitude of proportion of non-attributable costs in each expenditure item. Table 7 summarizes the magnitudes of non-attributable cost in percentage in some of the previous cost allocation studies.

Since non-attributable costs are not caused by traffic or vehicle use, the equity criteria are not directly applicable and there is no single criterion or cost-allocator which can be used to distribute these costs in a clear-cut and unambiguous way. A number of criteria have been used in previous studies for the allocation of non-attributable costs or common costs. However, they are mostly use-related criteria such as number of vehicles, vehicle-miles of travel, axle-miles of travel, and passenger-car equivalences.

A typical example is the procedure adopted by the 1980 Oregon study [26]. It allocated non-attributable costs mainly on the basis of vehicle-miles of travel. Only pavement striping and marking costs were allocated on the basis of axle-miles of travel.

Wisconsin study [36] presents an exception where non-attributable costs (termed as fixed costs in Wisconsin study) were assigned to each vehicle class in proportion to the attributable cost responsibility of the class. It was argued that assigning non-attributable costs by use-related criteria directly conflicted the definition that non-attributable costs do not vary with vehicle use. However, it is doubtful that Wisconsin's method provides a better procedure because by using the attributable cost responsibility proportion, one

Table 7. Percentages of Non-attributable Costs in Other Studies

Study	Items	Percentage of Non-attributable Costs	
Wisconsin (1982)	Highway Construction	0%	
	Structure Construction	0%	
	Highway Rehabilitation	15.3%	
	Structure Replacement	22.3%	
	Maintenance		11.0% of total costs
	(i) Roadside	38.0%	
	(ii) Wayside & rest areas	10.3%	
	(iii) Snow & ice control	0%	
	(iv) Pavement, shoulder, bridge	19.9%	
	(v) Traffic services	0%	
	Special Services	0%	
Oregon (1980)	Construction (including overlay)	15.0%	26.4% of total costs (Budget #1)
	Maintenance	24.7%	
	Pavement Damage	10%	
	Other Items	46.7%	
Maryland (1983)	Highway Construction		
	(i) New pavement	0%	
	(ii) Reconstructed pavement	25%	
	(iii) Major repaired pavement	25%	
	(iv) Other roadway items	0%	
	Roadway Maintenance	25%	
	Administration Costs	0%	
	Bridge Structure Costs	unknown	
North Carolina (1983)	-	environmental effects not separated	
Virginia (1982)	Pavement Maintenance		
	Interstate	22.6%	
	Primary	34.0%	
	Secondary	46.9%	

is actually following the weight-related and use-related criteria used in allocating attributable costs to allocate non-attributable costs.

The non-attributable costs, also known as common costs, were allocated in proportion to vehicle-miles traveled in the 1982 FHWA study [8]. The main reason for using this cost-allocator was simply that it has been used traditionally and is easily understood and accepted.

Allocation of Attributable Costs

Attributable costs include (a) costs which are entirely attributable to a single vehicle class, (b) costs which are attributable to a group of vehicle classes, and (c) costs which are occasioned by the entire traffic as a whole. In practice, the attributable costs of most expenditure items are types (b) or (c) or a combination of both. Appropriate equitable procedure and cost-allocators are required to distribute the cost occasioned to the vehicle classes involved for types (b) and (c) costs mentioned above.

In general, the 'incremental' concept has been the most commonly used method for allocation of attributable costs. Virtually all previous cost-allocation studies subdivide highway costs into increments in some way for allocation. The essence of the traditional incremental method can be briefly described as follows. The first increment of expenditure is the cost for providing the facility concerned for the basic vehicles where the term basic vehicles may refer to vehicles with the smallest gross weight, smallest axle weight or smallest width, depending on which parameter is used for defining the increments. This first cost increment would be assigned to all vehicles on the basis of a selected cost-allocator.

By arranging all vehicles in increasing order of the parameter, beginning from the basic vehicles, the number of increments is determined so that accurate and meaningful conclusions could be achieved. The second cost increment is obtained by adding the second increment of vehicles and the additional facility required to accommodate them is determined. This cost increment would be allocated to all vehicles in the second through the last increment, again by means of a suitably selected cost-allocator.

The method proceeds to compute incremental cost each time a new increment of vehicles is added, and allocate this cost according to vehicles responsible. It can be seen that with this procedure, the basic vehicle class is responsible, jointly with all other vehicle classes, for only the first cost increment; whereas the last increment of vehicles is jointly responsible for every cost increment. For convenience, we shall call this approach traditional incremental or the standard incremental method, regardless of the number of increments used.

The classical six-step incremental procedure was first used more than 20 years ago. Studies have been made using 15 or more steps in order to increase the accuracy of allocation. Unfortunately, when the cost increment is not a linear function of parameter increment, increasing the number of steps alone does not eliminate an inherent weakness of the standard incremental method. This is the so called economies of scale problem which leads to unequal cost increment, and hence unfairness, when equal parameter is added at different stages of the procedure.

The 1982 FHWA study [9] developed a refined version of incremental approach, designated as uniform removal technique, which practically elim-

inates the problem associated with economies of scale. In this method, each vehicle group is divided into a large number of groups and traffic is removed (instead of adding) uniformly across vehicle class. This is in effect a numerical integration procedure and is therefore superior to the BAR method used in Wisconsin study [36]. It is noted that in this refined version of incremental approach, the basic vehicles are no longer jointly responsible only for the first (lowest) increment. The basic vehicles are now, like all other vehicle groups, jointly responsible for every increment considered.

The present study also adopts the incremental concept as required by the H.E.A. 1006. In the following sections, detailed discussion of the proposed methodology for allocating the highway and structure costs is presented.

HIGHWAY CONSTRUCTION COST ALLOCATION

General

Highway construction costs are divided into the following items for cost-allocation purposes:

Right-of-Way costs

Grading and earthwork costs

Drainage and erosion control costs

Pavement costs

Shoulder costs

Miscellaneous costs

There are 874 contract sections of State highway in the IDOH Road Life Records. New construction project contracts are first identified. Cost information of these contracts is then extracted from Road Life Records, Construction Reports File and Itemized Proposal File. Further classification of these extracted costs is possible by highway type (Interstate, State Route or US Route, by surface type, concrete and bituminous) and by area type (rural, urban or mixed) from Road Life Records. Breakdown of each contract cost into the five allocation items mentioned above is derived from itemized costs available in Road Life Records and Itemized Proposal File.

Right-of-Way Costs

The total right-of-way width is the sum of the widths of the following elements: pavements, shoulders, medians and borders. Pavement, shoulder and median costs will be treated separately under headings of pavement costs and

shoulder costs.

Costs considered under right-of-way include acquisition costs of right-of-way, preparation costs of right-of-way, relocation cost, utility adjustment cost and roadside development costs. Since right-of-way requirements are not the same for different highway classes, it is necessary to separate right-of-way costs according to the types of highways. A more complex procedure is to classify right-of-way costs by highway class, terrain type, and location (urban or rural). An analysis of the cost data is needed to determine if a detailed classification of right-of-way costs is justifiable.

Depending upon the design practice used in each state, right-of-way cost may or may not be a function of vehicle characteristics. For instance, Maryland [32] considered all right-of-way costs to be basic cost, whereas in Wisconsin study [36], only 47.4% are basic costs, the remaining 52.6% are allocated by incremental method with vehicle-miles used as the inter-group cost-allocator. Oregon study [26] allocated right-of-way cost incrementally by observed gross weight of vehicles - gross weight is used as a proxy for vehicle size.

Of the various components of right-of-way costs, the land acquisition cost appears relatively easy to be allocated in the sense that it can be assumed to be proportional to overall right-of-way width. For other costs, there is no obvious logical procedure to be followed for allocation.

There is no specific right-of-way width requirements in Indiana. Generally the AASHTO standard [1] is adopted in practice. A summary of AASHTO right-of-way width design guidelines is shown in Table 8. These design widths are applicable for rural highways where land acquisition is not a major

Table 8. Right-of-Way Width Requirements

Highway Type		Right-of-way Width (ft)
2-lane	low type surface	66-80
	intermediate type surface	80-100
	high type surface	100-120
4-lane divided highway	restricted	90-110
	intermediate	140-180
	desirable	210-310
6-lane and 8-lane highways		add width of 12-ft lanes to 4-lane right-of-way width

problem. Such widths are usually not attainable in urban highway construction.

An incremental approach may be developed for right-of-way costs on the basis that right-of-way width bears some relationship to design-hour volume expressed in passenger-car equivalents. This approach is not proposed in the present study for the following reasons:

1. As traffic volume increases, wider pavement, shoulder and median are needed to provide certain desired level of service. Wider right-of-way is required as a result. However, an increase in traffic volume generally represents a proportionate increase in all classes of vehicles rather than in a particular class of vehicle.

2. Greater width requirement represents a relatively small percentage of total right-of-way width. For a rural 4-lane highway with a right-of-way width of say 200 feet, an additional width of 8 ft accounts for only 4% of total width. Any additional responsibility of truck is likely to be offset by the automobile responsibility mentioned in item 3.

3. Wider highway is designed to accommodate peak traffic volume. For both rural and urban highways, studies [13] have indicated that the percentage of passenger cars and light trucks in design-hour volume is higher than their percentage in average daily traffic. On this aspect, passenger cars and light trucks tend to have higher responsibility than their percentage in ADT suggests.

The present study defines two components of right-of-way costs. The first portion of cost corresponds to a minimum right-of-way width as defined

by the AASHTO standard [1] - 66 feet for 2-lane highway, 90 feet for 4-lane, 108 and 120 feet for 6 and 8 lane highway, respectively. These form non-attributable portions of the right-of-way cost which is to be shared by all vehicles using the highway. The vehicle-miles of travel, which measures the relative use of highway by different vehicle classes, is used to allocate this common cost. The right-of-way costs of any highway with a right-of-way width below the stipulated minimum will be allocated entirely on the basis of VMT.

Any additional width above the stipulated minimum, which leads to the second portion of right-of-way costs, can be considered to be capacity-related requirement. As such, they should be allocated in proportion to passenger car equivalent (PCE) - miles of travel.

In summary, the common cost portion of right-of-way costs is computed as the ratio of minimum right-of-way width to the actual width of the right-of-way. This cost portion is allocated on the basis of VMT. The remaining right-of-way costs are allocated according to VMT weighted by PCE.

Grading and Earthwork Costs

Most studies consider the amount of grading and earthwork to be related to vehicle width and thus is a function of pavement width. Maryland study [32] divided these costs into two increments, namely the base facility costs for automobiles and the second increment for trucks and buses. The cost-allocator used within the two increments is PCE-miles of travel. Based upon the design criteria for different terrain characteristics, Wisconsin study [36] utilized computations for three standard terrain types (flat, rolling and hilly) to estimate the effect of different vehicle sizes. An incremental

analysis based on vehicle width was then used to allocate grading and earthwork costs. Oregon study [26] also allocated these costs incrementally by observed gross weight of vehicles.

In the present study, initially the costs for roadbed excavation, filling, leveling and compaction, will be combined into a single cost. This is done in order to make use of the available data from cost files which contain individual costs for these items.

Following the same approach as in allocation of right-of-way costs, the grading and earthwork costs associated with a minimum road width is specified as common costs to be shared by all vehicles. Cost associated with additional road width in excess of the minimum is considered to be facility needed to satisfy capacity and level of service requirements. For the first portion of costs which correspond to work performed within the minimum road width, the cost-allocator is vehicle-miles of travel. The remainder of the costs is to be allocated on the basis of PCE-miles of travel.

AASHTO design guides [1] for traveled way widths are adopted for defining the minimum widths which are computed as the sum of minimum widths of pavement, median and shoulder, as shown in Table 9.

A refinement in the allocation of grading and earthwork costs would be possible if compaction costs could be extracted from the cost data. This compacted subgrade layer is frequently included in pavement design as a structural component of flexible pavement [37]. It serves to reduce the structural requirements of the pavement resting on it. It would therefore be more logical to distribute the compaction costs with a weight-related cost-allocator.

Table 9. Traveled-Way Width Requirements

Highway Type	Min. Traveled - Way Width (ft)
2-lane highway	26
4-lane highway	44
6-lane highway	56
8-lane highway	68

The costs of excavation in rolling or hilly terrain require a more detailed allocation procedure. Studies [14,30,34] have shown that the rate and length of a given grade have more effects in reducing the speeds of heavy vehicle. It has been found that the travel speed of vehicles on grades is a function of their weight-power ratio. AASHTO [1] provides recommended critical length of grade for design based on the requirement of heavy trucks with a weight-power ratio of 600 pounds per horsepower. Similar critical length and rate of grade relationships can be derived for other weight-power ratios. An incremental approach for allocation of grading costs in rolling or hilly terrain may be developed based on the different critical length and grade requirements of vehicles with different weight-power ratios.

This refined analysis was found unnecessary for the present study for the following reasons. Construction records for the base period (1980-83) show that most of the construction projects were reconstruction which were mainly improvements involving very little or no excavation of slopes. Of the few new construction projects completed within the base period, the length constructed in each project was relatively short. None of these construction projects were found to involve critical length consideration. The pattern of future construction in the analysis period (1985-86) is expected to remain the same, that is, predominantly reconstruction to improve geometric features and safety. Exclusion of critical length analysis for excavation costs therefore would not have any significant effect on the overall grading and earthwork cost-allocation.

Drainage and Erosion Control Costs

Highway drainage facilities are constructed to remove storm water from

paved roadway as well as across the entire width of the right-of-way. Properly designed highway drainage facilities are essential to erosion prevention and control. The extent of drainage facilities and erosion control measures required is directly related to the amount of runoff expected. A logical allocation parameter for drainage and erosion control costs is therefore the runoff quantity which, for a given rainfall intensity, is a function of the area and surface type of the runoff watershed concerned.

Virtually all previous cost-allocation studies chose to combine drainage costs with grading costs and these costs were allocated largely on the basis of VMT or PCE-VMT. However, recognizing the distinct feature of design consideration concerning drainage and erosion control facilities as discussed in the preceding paragraph, it was decided in the present study to treat the costs associated with providing these facilities separately from grading and earthwork costs.

The allocation procedure for drainage and erosion control costs adopted in this study has its basis on the long-used rational method for runoff estimation. This method is still the most practical approach for calculating the peak rate of runoff for roadway. The basic equation is:

$$Q = ciA$$

where,

Q = peak rate of runoff, in cfs;

c = runoff coefficient;

i = rainfall intensity in in/hr;

A = watershed area in acres.

For heavily vegetated area, the runoff coefficient is taken as 0.2 and for paved surfaces, it is 0.9. This means that, for a given rainfall intensity, a unit area of paved surface would produce 4.5 times as much runoff as that from a unit area of vegetated ground. Using this value of 4.5 as weighting factor for paved surfaces, the cost-allocating procedure proceeds as follows:

i. The total drainage and erosion control cost is first split into two components, namely paved-surface responsibility cost, and non-paved-surface responsibility cost. These two cost components will be computed in proportion to their respective weighted widths. Paved surface is basically the roadway itself and the weighting factor is 4.5. For non-paved surface, the weighting factor is 1.0.

ii. The paved-surface responsibility cost will be allocated by first defining a minimum roadway width. This minimum roadway width is the sum of minimum traveled way width and minimum shoulder width, specified respectively in Table 9 and in section on allocation of shoulder costs. Cost associated with the minimum roadway width will be allocated as common cost on the basis of VMT. Cost corresponding to additional roadway width in excess of the minimum will be allocated on the basis of PCE-miles of travel.

iii. The non-paved-surface responsibility cost will be allocated by considering minimum non-paved-surface width which is given by the difference between minimum right-of-way defined in Table 8 and the minimum roadway

width computed in Step ii above. Again, costs associated with the minimum width will be allocated on the basis of VMT, and that associated with excess width on the basis of PCE-VMT.

iv. For each vehicle class, its total cost responsibility is given by the sum of its respective cost responsibility computed in Steps ii and iii.

New Pavement Costs

This section covers allocation of costs for constructing new pavement only. Cost of repair for pavement deterioration with age or pavement damage through vehicle use are dealt in the section on rehabilitation cost allocation. Because of this distinction, it is decided that allocation of new pavement cost will not be based on wear-related criteria. Instead, occasioned costs would be determined by analyzing engineering details involved in the design of pavement. The appropriate costs will be assigned to the responsible vehicle class or classes accordingly.

The procedure of rigid and flexible pavement design adopted by IDOH [38] forms the basis of engineering analysis for pavement cost in this study. This procedure follows essentially the method outlined in 1980 AASHTO Interim Guide for Design of Pavement Structures [2]. Traffic loadings are expressed in terms of equivalent 18-kip single axle load applications (ESAL) for design of both flexible and rigid pavements. Thickness of flexible pavement is obtained by converting the structural number of the pavement concerned using Indiana material factors recommended by IDOH [38]. The structural number, determined with charts in AASHTO Interim Guide [2], is a function of serviceability index, soil

support value, regional location, ADT factor and total 18 kip single axle load applications. Thickness of rigid pavement is derived directly from charts in AASHTO Interim Guide [2] with the following input data: serviceability index, modulus of subgrade reaction, load transfer factor for reinforced concrete (RC) pavement, working stress and modulus of elasticity of concrete, ADT factor and total 18 kip single axle load applications.

Traditionally, pavement thickness costs have been allocated using the standard incremental method [18] developed almost two decades ago. However, recent research on pavement performance suggests several drawbacks of the traditional incremental method of new pavement cost-allocation. The most important drawback is that this method arbitrarily assigns the benefits of economy of scale to heavier vehicles [9].

A revised incremental procedure has been developed in the present study aiming to (i) overcome the problem of economies of scale in pavement cost-allocation, and (ii) be in consistence with the design procedure used in Indiana.

The proposed cost-allocation procedure, known as the Thickness Incremental Method, begins by defining pavement thickness increments, in contrast to the common practice of starting with traffic increments or decrements. There are two advantages with the proposed approach: (a) by beginning with a given thickness, no iterative procedure is necessary in calculating ESALs; (b) because pavement cost is more directly related to pavement thickness than traffic loading, a better control over the accuracy of the result can be achieved by using pavement thickness as the

starting parameter.

In defining the number and magnitude of pavement thickness increments, the minimum practical pavement thickness must first be determined. Following AASHTO Interim Guide [2] recommendations, the following minimum thicknesses are considered to be the basic cost components which are required for flexible pavement regardless of the traffic level:

Surface Course	1 inch
Base Course	3 inches
Subbase Course	4 inches (if subbase is used)

For rigid pavements, the minimum thickness is taken as 4-1/2 inches. Only those costs corresponding to the thickness in excess of the specified minimum will be allocated by the incremental approach described in this section. The pavement costs associated with the minimum thickness will be allocated on the basis of VMT.

The total thickness in excess of a specified minimum is divided into increments, the number and thickness of which depend on the desired accuracy of the final results. Beginning with the specified minimum thickness, a thickness increment is first added. With this total thickness, the ESAL of each vehicle type or a representative vehicle type of a vehicle class can be computed directly from the following equation which was developed from the AASHO Road Test [2,12]:

$$\text{Log ESAL}_x = G_t \left[\frac{1}{b_{18}} - \frac{1}{b_x} \right] + \text{Log} \left[\left(\frac{L_x + L_2}{19} \right)^A / L_2^B \right]$$

where, $ESAL_x$ = equivalent single axle load of axle type x;

G_t = a function of the ratio of loss in serviceability to the potential loss taken to a point where terminal serviceability index (p_t) is 1.5;

b_x = a function related to axle weight of vehicle type x, pavement strength and pavement thickness;

b_{18} = a function related to a single axle weight of 18 kips, pavement strength and pavement thickness;

L_x = axle load in kips;

L_2 = 1 for single axles, 2 for tandem axles;

A = 4.79 for flexible pavement, 4.62 for rigid pavement;

B = 4.33 for flexible pavement, 3.28 for rigid pavement.

In calculating ESAL with the above formula, Indiana practice [38] is followed. A terminal serviceability index p_t value of 2.5 or 2.0 is used for flexible pavement, and 2.5 for rigid pavement. The following material constants are used for computing pavement strength:

Bituminous Surface = 0.4/inch

Bituminous Binder = 0.34/inch

Bituminous Base = 0.3/inch

Bituminous Stabilized Subbase = 0.24/inch

Compacted Aggregate Type "p" = 0.14/inch

Granular Subbase = 0.08/inch

The same procedure is repeated for each additional increment until the total thickness is reached. The incremental pavement thickness cost corresponding to each thickness increment is assigned to all vehicle classes based on their need for that thickness according to pavement design procedure. Accordingly, the proportional amount of pavement thickness cost attributable to a given vehicle is in direct proportion to its ESAL value. With the same reasoning, the proportional cost responsibility of a given vehicle class is equal to its proportional contribution to the total ESAL of the entire traffic stream.

At any given pavement thickness, it is possible to calculate the corresponding total ESAL. However, this information is not essential because only the proportional contribution of ESAL from individual vehicle classes are needed. It can be logically assumed that the traffic responsible for any intermediate pavement thickness has the same vehicle class composition as that of the actual traffic stream for which the total pavement thickness is designed. Since the proportions of individual vehicle classes in the entire traffic stream are known, their proportional ESAL at any given pavement thickness can be obtained by multiplying each vehicle class traffic proportion by a single vehicle ESAL representative of the vehicle class. However, as the procedure can be made more accurate with information on axle weight distribution within

each vehicle class, the analysis in the proposed study will be performed in terms of axle weight groups. Extending the idea further, the same cost-allocation procedure can be even followed using individual vehicle type, instead of vehicle class or axle weight group, as the basic unit. This means that a separate within-class cost-allocation step is not necessary with the proposed procedure.

By having each vehicle class proportionally represented each time an incremental cost is allocated, the cost-allocation procedure described above effectively eliminates the economies of scale problem associated with the traditional incremental method. It also allocates all pavement thickness in excess of a specified minimum in consistence with thickness design concept and avoids the problem of having an unaccounted for residual thickness as is found when using Wisconsin's BAR method [36]. Iterative procedure which is a routine in all existing methods is bypassed by taking thickness increment as the starting parameter. Furthermore, the procedure is easy to understand because it follows the usual thinking of increasing pavement thickness to account for increasing traffic. A description of the computational algorithm of the thickness incremental method is presented in Appendix A.

For new pavement width in excess of a specified minimum pavement width, a slightly modified allocation procedure is required. A pavement width of 9 feet per lane is taken as the minimum width in the present study. The portion of pavement width in excess of 9 feet is allocated by the same incremental allocation procedure described earlier, except that the pavement costs associated with each extra thickness increment for the additional width are allocated differently. Instead of allocating

according to the each vehicle class' share of total ESAL, a combination of PCE and ESAL is used as the allocator. This is in recognition of the effects larger vehicles have on roadway width and roadway capacity.

Shoulder Costs

In previous highway cost-allocation studies, shoulder costs have been handled in several different ways. Some studies [6] suggest that shoulder and pavement costs be grouped together on the assumption that both costs are occasioned by the same vehicles in the same proportions. Other studies [22,36] treated shoulder costs separately using a minimum width approach by assuming certain shoulder width is required by all vehicles. Any width in excess of this minimum is taken to be occasioned by larger vehicles.

In the process of selecting a procedure for allocating shoulder costs in the present study, the major functions of a shoulder need to be first examined. The AASHTO Manual on Geometric Design [1] lists the following shoulder functions:

1. Space is provided for stopping free of the traffic lane due to motor trouble, flat tire or other emergency.
2. Space is provided for the occasional motorist who desires to stop to consult road maps, to rest, or for any other purpose.
3. Space is provided to escape potential accidents or reduce their severity.
4. The sense of openness created by shoulders of adequate width contri-

butes much to driving ease and freedom and strain.

5. Sight distance is improved in cut sections and, thus, hazard is reduced.

6. The capacity of the highway is improved. Uniform speed is encouraged.

7. Space is provided for maintenance operations.

8. Lateral clearance is provided for signs and guard rails.

9. Storm water can be discharged farther from the pavement and seepage adjacent to the pavement minimized.

10. Structural support is given to the pavement.

Strictly speaking, only items 1, 2 and 3 are affected by the presence of trucks. It is therefore not entirely correct to claim that shoulder width in excess of a certain minimum is due completely to larger or heavier vehicles. Consequently, it appears that an equitable approach is to allocate excess width costs on the basis of PCE-VMT, which is a parameter more closely related to capacity and level of service considerations.

In allocating shoulder thickness costs, it is realized that shoulder thickness is not designed for the same traffic loading as that for pavement. It may be argued, however, that the same percentage of cars and trucks in traffic stream will make use of the shoulder provided. If this assumption is true, then it would be acceptable to follow pavement cost-

allocation procedure.

A procedure must be developed to satisfy both the shoulder width and thickness criteria described above. Shoulders of 2-foot and 6-foot are considered to be the minimum widths in this study for 2-lane and 4-or more lane highway, respectively. This implies that the costs of all shoulders with width less than the minimum would be allocated using the incremental approach developed for pavement cost-allocation. For shoulder width in excess of the minimum, the corresponding cost in proportion to width is allocated by the same procedure, but with the allocative parameter weighted by PCE.

Reconstruction Costs

Reconstruction involves construction on approximate alignment of an existing route where old pavement may be removed and replaced. It includes widening projects which provide additional width to existing pavements; improvements of highway geometry such as realignment of roadway on existing right-of-way, and upgrading of unsafe features.

For these reconstruction projects which involve removal of old pavement, pavement and other cost items will be allocated with the same procedure as that for new construction. In many cases, reconstruction projects recorded in the IDOH construction records included other incidental improvements such as resurfacing of adjoining existing pavement in a roadway realignment project or resurfacing of existing lanes in a widening contract. These resurfacing costs will be separated from new pavement construction cost, and allocated by means of rehabilitation cost-

allocation procedure discussed in a later section of this report.

Other expenditures such as right-of-way, shoulder, drainage improvements and earthwork costs in reconstruction projects will be allocated using the same procedure developed for allocating the corresponding items in new construction.

Miscellaneous Items

Construction costs of items not allocated under the four cost categories discussed in previous sections will be considered individually to determine the cause for incurring these costs and the appropriate cost-allocator to be used.

Engineering services, installation of traffic control devices, pavement marking are examples of cost items which cannot be allocated specifically to any vehicle groups. These costs can be treated as common costs and allocated on the basis of VMT, which is a measure of the relative use of highway by various vehicle groups.

For items which are mainly for a specific group of vehicles, the corresponding costs should be allocated accordingly to this vehicle group only. Some examples are construction of climbing lanes and weigh stations. These facilities are constructed exclusively to serve heavy vehicles. Cost of these items should therefore be allocated entirely to these vehicles. Further within-group distribution of these costs can be based on VMT.

HIGHWAY REHABILITATION COST ALLOCATION

General

Rehabilitation can be considered as a large scale maintenance operation in the sense that both rehabilitation and maintenance aim at maintaining ride quality and structural condition. They are different, however, since maintenance refers to minor activities which are carried out routinely, whereas rehabilitation activities are required only when routine maintenance operation can no longer maintain the quality of highway desired. It is therefore important to realize in allocating expenditures of a highway item, particularly pavement related expenditures, that although the causes for maintenance and rehabilitation operations are usually the same, there is a significant difference in scale of the deterioration associated with the operations.

Rehabilitation costs in this study are defined as being the expenditures spent to restore the level-of-service of highways in Indiana. Rehabilitation consists of major reconstruction or resurfacing activities that are not classified and coded as routine maintenance activities of IDOH.

Previous Studies

Only a few previous cost-allocation studies treated rehabilitation as a separate expenditure category. A majority of these studies grouped rehabilitation costs with construction costs and allocated them based on the same methods used for allocating construction costs [21,26,32]. The 1982 Virginia study [17] separated rehabilitation projects into

construction and maintenance categories. Rehabilitation costs were included in construction costs and allocated accordingly if rebuilding occurred along with improvement in capacity, alignment, grade or other features of roadway geometry. Otherwise, they were allocated as maintenance costs.

Wisconsin study [36] allocated rehabilitation costs separately from construction and maintenance costs. Rehabilitation costs were divided into basic, service, and fixed portions. The basic portion included costs required to provide the level-of-service to accommodate the passenger cars. The service portion of costs were required to provide a level-of-service beyond the basic level-of-service. Fixed costs were the costs resulted from natural phenomena. Different methods and cost-allocators were employed to allocate these three types of costs.

In most cases, previous studies allocated common costs based on VMT and traffic attributable costs based on weight-related cost-allocators, such as ESAL, axle-miles, and ton-miles although the methods may vary among the studies. The decision to estimate rehabilitation costs caused by weather only was primarily based on engineering judgments.

The recent FHWA Cost-Allocation Study [8,27] recommended an approach to allocate rehabilitation costs using a series of distress functions. The distress functions were developed for the most important distress types for both flexible and rigid pavements and four different climatic zones were considered. Appropriate load equivalency factors were generated to represent the interaction of traffic and weather in causing a particular distress. These equivalency functions can then be used to

allocate rehabilitation costs, once the proportion of these costs occasioned by individual distress types are identified.

FHWA model [27] developed for application in nationwide study is not directly applicable to any state level analysis without considerable amount of modification. In addition, FHWA study did not consider routine maintenance costs since routine maintenance is the charge of individual state highway agencies. Consequently, the FHWA procedure does not provide any criterion for differentiating rehabilitation responsibilities from routine maintenance responsibilities of vehicle classes. If FHWA procedure were to be used for allocating rehabilitation costs at state level, one would be confronted with the problem of what type of damage or distress functions should be used for allocating routine maintenance costs. Double counting appears to be unavoidable if a damage function approach is also used for allocating routine maintenance costs.

Allocation Procedure for Pavement Rehabilitation Costs

Rehabilitation and routine maintenance, though involve different forms of activities and end results, are interdependent and closely related. It is important that a consistent unified approach be used for allocating rehabilitation and routine maintenance costs so that rehabilitation responsibilities could be separated from routine maintenance responsibilities, and that no double counting would occur. Described in this section is a proposed procedure for allocating pavement rehabilitation costs, which presents an attempt to satisfy the above requirements. The corresponding procedure for allocating routine maintenance costs is presented in a subsequent section.

Pavement design procedures adopted by Indiana DOH has been described in the section on allocation of new pavement costs. Following this design concept, it implicitly implies that, in an ideal situation where the design conditions are correctly predicted, a pavement constructed accordingly would be able to serve the design traffic until the end of its design life when the pavement PSI reaches a predetermined terminal PSI level at which a rehabilitation is deemed necessary to restore the pavement PSI to its original as-constructed level.

It is logical to say that the cost incurred in designing and constructing the original pavement has accounted for the pavement wear caused by traffic over the period of its design life. The purpose of rehabilitating the pavement is to give it another service life span to serve the traffic. The vehicle classes that use the rehabilitated pavement must therefore pay for the rehabilitation cost. With this reasoning, a cost allocation concept similar to that used for allocating new pavement cost is proposed.

Consider again the ideal design conditions and assume that a decision to rehabilitate a pavement is made at the end of the design life of the pavement. If there is no other factors additional to those for which the pavement was designed, the rehabilitation costs incurred would be due to design factors only and therefore have to be shared by all the vehicles that would be using the rehabilitated pavement.

There is no standard or generally accepted overlay design procedure available. <u>AASHTO Interim Guide</u> [2] classifies overlay design practice into several categories. For the purpose of the present study, the

AASHTO Interim Guide procedure is considered to be most suitable in that it provides consistency in approaches in allocating different components of pavement costs.

The basic idea of the AASHTO Interim Guide [2] approach for overlay design is to subtract the existing pavement structure thickness from the total thickness required by a new design analysis. In using this procedure, in addition to a soil support value, each of the existing layers is assigned a layer coefficient.

In a cost-allocation analysis, the thickness of overlay constructed is known from the base year data. It is not necessary to go through the design computation again. The procedure developed in the present study for allocating new pavement costs, namely the Thickness Incremental Method, can be applied to allocate the part of the rehabilitation cost related entirely to traffic based upon the thickness of overlay constructed.

Factors other than traffic loading which is the primary factor in Indiana pavement design procedure, are also responsible for the loss of PSI of a pavement. These non-traffic factors include severe weather and de-icing chemicals, faults in engineering design, defects in material used, and poor construction quality. If no routine maintenance were carried out, a pavement performance in terms of PSI would fall below the PSI curve predicted by pavement design equations as shown in Figure 2.

In Figure 2, area A represents a measure of the pavement wear or damage due to traffic and other design factors, and area B represents the further pavement wear due to non-traffic factors and interaction of

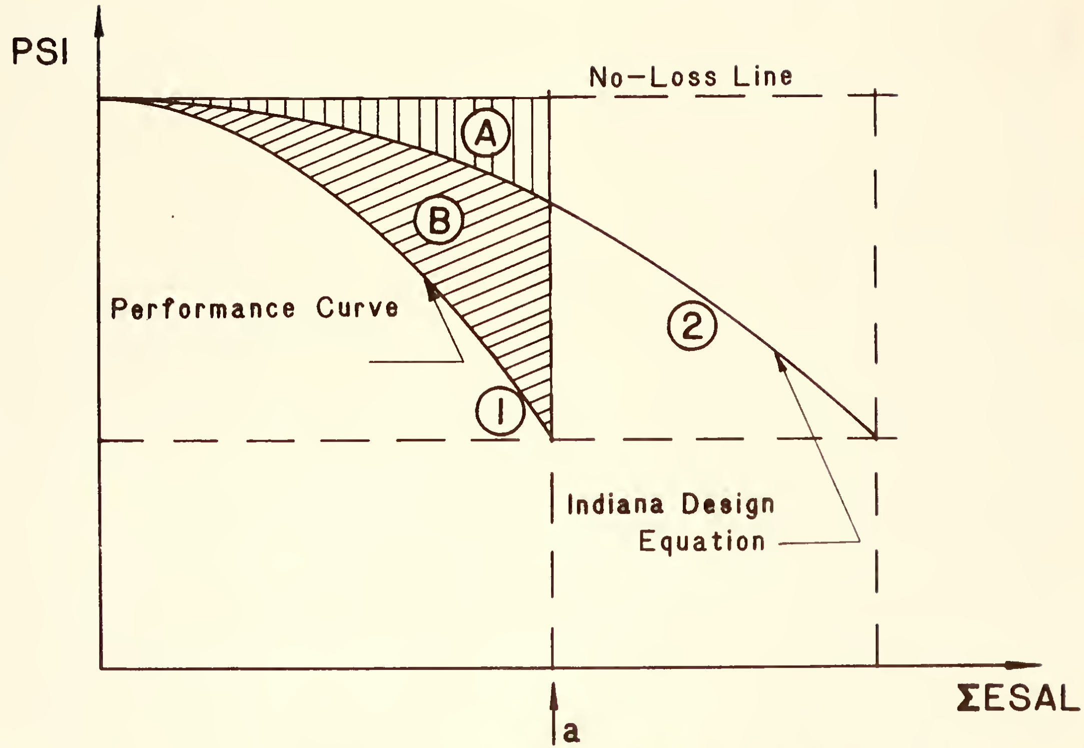


Figure 2 Schematic Diagram Showing Pavement Performance Considered in Highway Rehabilitation Cost Allocation

traffic and non-traffic factors. We may conclude that the proportion of design-factor related rehabilitation costs is given by $(\frac{A}{A+B})$.

The non-traffic plus interaction effects are responsible for $(\frac{B}{A+B})$ of the costs for rehabilitation at stage 'a'. This portion of the rehabilitation costs would have to be further divided into traffic-related and non-traffic related costs. Direct allocation on the basis of a cost allocator such as VMT or ESAL is undesirable because such approach does not differentiate between traffic and non-traffic effects. Delphi technique has been used in some studies to obtain the proportional responsibility of traffic and non-traffic effects. However, on a topic such as this where there is a wide disparity of views among highway pavement experts, it is doubtful that efforts to find averages from pooling opinions would produce any meaningful results.

A methodology has been developed for use in the present study to determine the responsibilities of load-related and non-load-related factors for pavement routine maintenance and rehabilitation costs. The procedure involved is described in detail in Appendix B.

As design criteria are different for different climatic regions, highway classes and types of pavement, it is necessary to group pavements by region, highway class and pavement type. In the present study, two regions, five highway classes and four pavement types are being considered. The two regions refer to northern and southern Indiana. The five highway classes include Interstate, state routes primary, state routes secondary, city streets and county roads. The four pavement types are flexible pavements, rigid pavements with bituminous overlay, JRC and

CRC pavements. Appropriate pavement wear responsibility factors are then developed by region, highway class and pavement type.

These factors are then to be used to compute load-related and non-load-related portions of the pavement rehabilitation cost of a given rehabilitation project. For the load-related portion of the cost, the Thickness Incremental Method will be applied for cost-allocation computation. In this instance, the original existing pavement thickness is taken as the basic minimum thickness with zero cost, and the incremental analysis will be carried out for the added overlay thickness. The non-load-related portion of the cost is considered to be common cost and it will be allocated on the basis of VMT.

STRUCTURE CONSTRUCTION AND REPLACEMENT COST ALLOCATION

General

In this section a discussion is presented on procedures of allocating the costs of highway structure construction and replacement to vehicle classes. Structural costs would include the costs for the new or replacement bridges, culverts, and sign structures. In addition, structure rehabilitation cost would include the cost of such items as bridge deck replacement.

The classical incremental method which involves repetitive designing of a given bridge structure for different vehicle loadings is still the commonly used method for allocating bridge structure costs. The 1982 Wisconsin study [36] used designs for 3 types of bridges: prestressed concrete girder, RC launched slab and steel plate girder bridges. A few typical span lengths were chosen for analysis purposes and 5 AASHTO design live loadings [3] were used to approximate different vehicle loadings. The 1983 Maryland study [32] followed a more elaborate procedure by performing incremental analyses separately for bridge decks, superstructures, substructures and miscellaneous elements. The 1982 Virginia study [17] also used the standard increment procedure but used only 4 increment of vehicles. Five bridge designs were judged to be representative of all bridge construction projects. In FHWA study [8,9], a bridge was first designed for full design loading, and cost reductions were then calculated by removing vehicles group by group, starting from the group with the heaviest vehicles.

In the following, the general concept along with some specific allocation methods to conduct an incremental study are briefly described. This is followed by a summary of the typical methodologies adopted by previous studies. A general procedure proposed for the present study is then described, and possible alternatives are discussed. These alternatives will be considered after the proposed procedure is completed to substantiate the accuracy of the present study.

Approaches to Incremental Structure Cost Allocation

Incremental approaches to structure cost allocation are generally based on a set of bridge structure designs for a standard set of vehicle loadings, defined by the AASHTO [3]. Based on the structural design, costs are allocated for each component of structures, and hence the cost increments due to each HS and H vehicle design loads can be evaluated. If the design loads can be correlated to the basic classification of vehicles, such as the gross vehicle weight (GVW), then the cost increments can be defined according to the vehicle classification. Thus, the analysis for a cost-allocation of bridge structures can be categorized into three specific tasks: (1) the correlation of the vehicle classification to the AASHTO design loads, (2) the design of highway structures according to the specified design loads, and (3) the allocation of costs to each structural design, and hence to each vehicle classification.

Design Loads

Vehicle live load for highway bridges is usually specified by design lanes and lane loads. Each lane load is represented by a standard truck

with trailer or, alternatively, as a uniform load superimposed by concentrated loads. The truck loads are usually designated as H or HS loads in AASHTO specification. Typical loads used are H-20 and HS-20. An H-20 load simulates a two-axle single truck with a 14-foot wheelbase and a total weight of 20 tons. An HS-20 load is a three-axle tractor-trailer combination with a variable wheel-spacing and a total weight of 36 tons. In design practice, axle loads of the design truck are to be positioned on the span along with the associated lane loads, so as to yield maximum stresses and deflections. Thus, three important parameters which specify the type of vehicle loads in bridge design are (1) the total vehicle weight, (2) the distribution of axle loads and (3) the axle spacings.

It is important to note that the basic AASHTO design loads are not the trucks operating on highways. Rather, they are index loadings to specify design criteria, although their configurations were originally developed to simulate the most severe live loads operated on public highways. For actual design purposes, they are quite adequate and can be viewed as real live loads with a considerable built-in safety margin. However, for the cost-allocation study, a quantitative correlation between the real trucks operating on the highway and the design index loadings must be established in order to assign accurately the cost increment to a specified group of vehicles.

A number of previous studies recognized the necessity to establish such a correlation, and found simple relationships for this purpose. Usually, the correlation relates only the gross vehicle weight (GVW) to the vehicle design increment. The other factors, such as the axle load distributions and axle spacings, were neglected. One of the difficulties in

adopting such a simple approach for the present study is that the basis of such a correlation is often not clearly justified in the literature. Thus, validation of the approach and extension to other vehicle classifications are not possible.

A more rational and seemingly more accurate approach is to use the equivalent load approach. This was suggested in the Maryland study [32], where the actual highway vehicles were categorized into seven basic classifications with different weight classes. The AASHTO design loads were divided into 59 possible GVW groups. Each group was identified by its design axle loading and axle spacing. To find the correspondence, each weight class in the basic truck group was represented by loads acting on a simple span bridge, with the span length ranging from 42 to 400 ft. The maximum moment at the center span was calculated. The same was performed for the 59 possible GVW loadings. A correlation analysis was then performed through a linear least-squares fit using the data, and an analytical relationship was obtained. To facilitate the curve-fitting procedure, a range number was adopted to identify the H and HS vehicles with a total of 27 ranges.

The Maryland approach [32] appears to be more comprehensive since the effects of the axle spacing and bridge type were accounted for. However, it is limited to a simply-supported single span bridge structure. Some errors may be introduced in extending the analysis to bridges with continuous spans.

Incremental Design of Bridge Structures

In an incremental approach a group of bridges representative of the

majority of structures constructed during the base period is selected. A basic structure is then be designed with minimum design load for each of the selected sites but with same structural characteristics as the constructed bridge. Next, a set of designs is undertaken for each site with additional increments of design load upto the load for which the bridge was originally designed. The increments are established on the basis of vehicle classification used in a particular cost-allocation study and the correlation factors of the vehicle loads with AASHTO design loadings. The basic structure represents the minimum requirements for the structural components. In the Wisconsin study [36], a 24 ft. roadway and one layer of steel bar reinforcement for concrete slabs with slab depth of 5 inches were considered to be the minimum. Such a design depends largely on the engineer's judgment and varies with the bridge type, span length, and the crossing type. The Wisconsin study considered the following:

Bridge Type	Span Lengths (ft)	Crossing Type
Prestressed Concrete Girder	35 1/2, 79	Highway
Reinforced Concrete Haunched Slab	32,53	Highway
Steel Plate Girder	112	Highway
Prestressed Concrete Girder	55	Waterway
Reinforced Concrete Flat Slab	32	Waterway
Steel Plate Girder	63 1/2, 79	Waterway

The structural types and span lengths were selected as the representative structures based on 150 bridges constructed in the State of Wisconsin during the base period (1977-80). The listed bridge types and

span lengths represent 96 per cent of the bridge constructed in that period.

For each bridge type and span length, a basic bridge was designed in the Wisconsin Study for the minimum vehicle load. In addition, variations in the design were also considered for highway systems serving different type of traffic. After the basic bridge structures were established, the structural components were upgraded for each increment of live load.

Incremental Cost Estimation

With the incremental design of bridge structures available, the cost associated with each increment of design can be evaluated using the contract bid records. Depending on the selection of the samples, and hence the total number of incremental designs required, reported studies in the literature generally fall under one of four approaches: (1) full-design method, (2) representative-bridge method, (3) semi-statistical method, and (4) heuristic method.

The full-design method uses all bridges constructed in a base period to find their incremental designs and associated costs. This method is generally regarded as the most accurate. However, considering the variability in other aspects of the cost-allocation study, the standardization of design procedures, and the required engineering judgment in the incremental designs, to adopt such a complex procedure is probably not necessary.

The representative-bridge method considers only a group of representative bridge types and span lengths selected from the base period. Detailed incremental design and cost evaluation are then performed only for the selected bridges. This method has been used extensively in recent cost allocation studies. The 1982 FHWA study [8] utilized the representative-bridge method to assign new structure costs. Bridges were selected to represent construction types for both grade separations and river crossings. Nine bridge types were selected and cost functions were developed for seven vehicle increments. The Wisconsin study [36] also used this approach with six bridge types of different span lengths. However, it should be noted that this method may suffer from large variability of costs, unless a sufficient number of representative bridge types is included.

The semi-statistical method is a simple but acceptable approach. In the Maryland study [32], it was suggested that this approach can minimize the effort needed in the incremental design. The procedure involves selecting two or more structures that are considered representative of the bridges constructed in the base period. A basic structure is then designed for each bridge for the minimum vehicle load. The costs for the basic structure are calculated and represented as percentages of the total costs of the constructed structure. The percentages are numerically fitted by a parabolic function of the vehicle loading, using a least-squares approach. The loading may be conveniently represented by a range number discussed earlier. Thus, cost factors for various load increments can be obtained from this data-fitted function.

Based on the Maryland study results, the method appears to be consistent with the results produced by the other methods. It requires considerably less design effort without affecting the level of accuracy.

The heuristic methods generally involve basing the cost allocation functions on various relationships believed to be consistent. For example, a direct proportionality may be assumed between the cost factor and the ratio of maximum stresses. Another approach is simply to use the cost factors in other studies. This can be justified since present bridge designs are standardized. Variation between states may not be too significant in the overall analysis of bridge costs of the same type and dimensions.

Critique

It has been suggested in the literature on cost-allocation studies that the allocation of structure costs should potentially be one of the most accurate methodologies. This is probably supported by the consideration that the design process for bridges is well defined. Hence, considerable efforts have been reported in improving the approaches for developing cost functions rather than emphasizing the procedure for incremental design. In this effort, vehicle loads have been considered into finer increments. Unit costs for the components and materials have also been considered in great detail. However, the necessity for such a detailed analysis and its significance in the final results are often not justified.

It is felt by the present study team that an area for improvement

lies in establishing correlation factors between the highway vehicle types and the AASHTO design loads. Though the question has been raised in several cost allocation studies, not much has been reported in terms of efforts to clear the ambiguity and to improve the accuracy. The lack of attention is probably due to a common misconception that the design loads are in fact the actual vehicle loading conditions of bridge structures. Without significant improvement in the procedure to relate bridge design loads to vehicle classification used in a cost-allocation study, the complex analysis suggested for the improved cost estimates and structural designs is incompatible with the overall accuracy and has little physical meaning.

Bridge Replacement Cost Allocation

Bridges are replaced due to the deficiencies of the original structures. Consequently, the FHWA study [8] treated bridge replacement costs differently from new bridge costs. A structural sufficiency rating was used to determine the relative contribution of each factors which were responsible. Costs were assigned to vehicles based on the sufficiency rating components. Deficiencies in original structures may include low load carrying capacity, inadequate lane width, fatigue worn components, and inadequate overhead clearances. In the present study the replacement costs will be analyzed to separate the portion of these costs that is related to load and dimensions of vehicles and the part that cannot be attributed to any particular vehicle class. Load and dimension related costs will be determined by considering the relative importance of vehicle loads and/or vehicle dimensions in the bridge replacement projects

considered. The common costs will include replacement costs due to aging and weather. The common costs will be allocated on the basis of vehicle-miles.

Bridge Rehabilitation Costs

Bridge rehabilitation costs are primarily for deck rehabilitation and the replacement of structural components. It can be argued that the majority of the bridge deck deterioration, particularly in northern Indiana, is due to weather and de-icing agents, especially for reinforced concrete bridges. However, traffic of heavier weights exacerbate the problem. A part of the cost to rehabilitate bridge deck can therefore be allocated using the approach proposed for highway rehabilitation. Other costs including those related to replacement of structural components can be considered to be the result of weather and de-icing chemicals, and therefore they can be treated as non-attributable common costs to be assigned to all vehicles.

Other Highway Structures

Construction costs of other structures can be allocated following essentially similar incremental approaches. However, the design of many of these structures is either insensitive to the vehicle weight classification, or totally independent of them. The allocation should therefore be made on the basis of type of structures considered. For example, design of box culverts with heavy overburden is insensitive to the vehicle loads, and hence the cost can be allocated as a common cost. Design of box culverts without overburden is, however, traffic-related and the

cost responsibility can be determined similar to flat slab bridges. On the other hand, the cost of sign structures is related to vehicle size. For lighter and smaller vehicles the horizontal and vertical clearances can be reduced and thus an incremental approach can be employed according to vehicle size.

Summary of Proposed Procedures

Based on a review of cost-allocation approaches reported in previous studies, a basic procedure and several alternatives are recommended for the allocation of structure related costs. Essentially, the basic procedure follows an incremental approach used in other studies with modifications to satisfy the unique features of Indiana practice. The alternative methods will be based on concepts either fundamentally different from, or requiring significant modifications in existing methods. It should be noted that the alternative approaches will be explored subject to the constraints of time and manpower, as they are in fact research subjects for further studies.

Basic Procedures

1. The correspondence factors developed in the Maryland study [32] will be adopted to correlate vehicle classifications to the AASHTO vehicle design loads.

2. The structure cost data for the base period will be identified according to the bridge design and contract bid record available.

3. A group of representative bridge structures will be selected from

the design record in the base period. The extent of utilization of a particular bridge structure type in different highway systems will also be assessed.

4. For each bridge type, an incremental design of the structure will be performed for each AASHTO vehicle design load. The design will follow the AASHTO specifications [3] and the recommended bridge design practice of IDOH.

5. Based on the contract bid record in the base period, the unit cost for each essential structural component and construction material will be established. Then, the cost for each incremental bridge design will be evaluated. Cost factors of the increments can then be obtained for each type of bridge structure and for each type of highway system.

6. Cost factors for the culverts and sign structures will be determined following appropriate incremental procedures for the same base period.

7. Total cost responsibility for a vehicle class will then be evaluated using the individual cost factors.

8. The procedure utilized in the Wisconsin study [36] will be followed as the primary reference.

Alternative Procedures

Possible adoption of several alternative approaches will be explored during the course of the study. The results may serve as a validation or comparison to the data obtained from the basic procedure.

1. A critical review of the existing methodologies for the allocation of structure construction costs indicated a major deficiency in the present procedures. That is, the vehicle classification derived from field observations cannot be accurately correlated to the AASHTO bridge design loads. Existing approaches are often based on an assumption that the AASHTO design loads are in fact real truck loads. Or, it is assumed that a direct relationship can be established independent of bridge types, vehicle geometry, or vehicle operating conditions. These assumptions are incorrect from the design point of view. An alternative approach of evaluating correspondence coefficients relating incremental vehicle weights to AASHTO index loads will be attempted in the present study. A direct approach can be to use a modified version of the simple correlation chart of the Maryland study. In particular, the modification of the Maryland chart would include the differences between a simply-supported span and a continuously supported bridge.

2. The cost evaluation aspect of the allocation method has been well examined in previous studies. However, the most widely adopted procedure has been the representative-bridge approach. Other methods such as the semi-statistical approach or a direct application of cost factors developed by other states have often been ignored. In the present study a follow-up analysis will be pursued to consider these alternative approaches as comparative measures to validate the results obtained from the basic procedure.

MAINTENANCE COST ALLOCATION

General

A particular item of maintenance cost can be classified as a "common" or an "attributable" cost. A common cost is a highway-related cost that cannot be specifically allocated to a class or classes of vehicles, and is therefore distributed among all highway users. For example, mowing of grass or the pick up of litter within rights-of-way can be considered as common cost. Common costs are to be borne by all users in direct proportion to the number of miles driven by each. Therefore, the common-cost allocator for each vehicle class is the VMT by that class as a percentage of the total VMT by all vehicle classes.

An attributable maintenance cost is a cost that can be directly allocated to a particular class or classes of vehicles. Attributable costs can be allocated on the basis of weight related allocators for those items that can be associated with vehicle weights. Some items can be allocated according to capacity related allocators when vehicle size affects the cost.

Previous Studies

Methodologies to allocate maintenance costs used by cost allocation studies by nine states were reviewed for comparison. These nine states are Connecticut, Florida, Maine, Maryland, North Carolina, Oregon, Washington, Wisconsin, and Virginia.

It was found from this comparison that there exists no universal method for the allocation of maintenance costs. This is especially true for the costs (pavement, shoulders and bridges) that are related to the weight of vehicles. The selection of cost allocators is based on various assumptions and reasonings. A majority of these states used ESAL as the cost allocator of pavement related maintenance costs. It seems however that the use of vehicle-miles of travel (VMT) has been accepted in most of the allocation studies for allocation of the common costs. Table 10 gives a summary of cost-allocators used by the nine states.

Proposed Methodology

Routine maintenance activities are classified into the following major groups:

1. Roadway and shoulder maintenance
2. Roadside
3. Drainage
4. Bridge
5. Traffic Control
6. Winter and Emergency
7. Public Service
8. Others

Roadway maintenance consists of activities such as patching, leveling, and sealing of cracks and joints. The associated pavement damages are considered to be caused either by climate conditions or by the interaction of climate and the weight of vehicles. The amount of maintenance costs related

Table 10. Maintenance Cost Allocators Used in Other Cost Allocation Studies

Study	Maintenance Cost Groups	Cost Split and Cost Allocators
Connecticut[1] (1982)	• Common Costs	100% to all vehicles by VMT
	• Traffic attributable costs	100% to all vehicles by ESAL-miles
Florida (1979)	• Surface	80% to all vehicles by axle-miles 20% to trucks and buses by ESAL and VMT.
	• Shoulders	85% to all vehicles by axle-miles 15% to trucks and buses by ESAL and VMT.
	• Resurfacing[2]	25% to all vehicles by axle-miles 75% to trucks and buses by ESAL and VMT.
	• All other maintenance	100% to all vehicles by VMT.
Maine (1982)	• Vehicle associated	100% to all vehicles; first to vehicle classes by a Delphi method, then by ESAL within the class.
	• Traffic associated	100% to all vehicles by PCE
	• Bridge superstructure	100% to all vehicles by ton-mile
	• Traffic remote	34% to all vehicles by VMT 66% to all vehicles as overhead[3]

1. Connecticut Study did not separate maintenance costs from construction costs.
2. This activity was administratively categorized as construction.
3. Overhead was distributed in proportion to the seem of all direct cost allocation. Overhead accounted for 27% of the total maintenance costs.

Table 10. Maintenance Cost Allocators Used in Other Cost Allocation Studies (Continued)

Study	Maintenance Cost Groups	Cost Split and Cost Allocators
Maryland (1982)	A. <u>Incremental Method</u> • Roadway & Shoulders	100% to all vehicles by axle-miles
	• All other maintenance	100% to all vehicles by VMT
	B. <u>Modified Federal Primary Method</u> • Roadway/Shoulders/Structures	75% to all vehicles by use/damage factors (ESAL) 25% to all vehicles by PCE-VMT
	• All other maintenance	100% to all vehicles by PCE-VMT
North Carolina (1983)	• Pavement-related	55% to all vehicles by weighted axle-miles[4] 45% to all vehicles by VMT
	• All other maintenance	100% to all vehicles by VMT
Oregon (1980)	• Surface and Shoulders	90% to all vehicles by ESAL 10% to all vehicles by axle-miles
	• Guardrails & fences, structures, drainage	100% to all vehicles incrementally by observed gross weight
	• Pavement striping & marking	100% to all vehicles incrementally by axle-miles

4. Operating weights were used for North Carolina study.

Table 10. Maintenance Cost Allocators Used in Other Cost Allocation Studies (Continued)

Study	Maintenance Cost Group	Cost Split and Cost Allocators
Oregon (1980) (continued)	• Roadside vegetation, roadside clean-up, traffic control facilities, snow & ice, and extra ordinary maintenance	100% to all vehicles non-incrementally by VMT
	• Studded tire damage	100% non-incrementally to cars only
Washington (1977)	• Pavement and shoulders	100% to all vehicles by axle-miles
	• All other maintenance	100% to all vehicles by VMT
Wisconsin (1982)	• Pavement, shoulders, and bridge	81% to all vehicles by ton-miles 19% to all vehicles as overhead[5]
	• All other maintenance	88% (average) to all vehicles by VMT 12% (average) to all vehicles as overhead
Virginia (1982)	• Pavement repair[6]	34.5% (average) to all vehicles by VMT 65.6% (average) to all vehicles by ESAL
	• Shoulder maintenance[7]	79.3% (average) to all vehicles by VMT 20.7% (average) to trucks by VMT
	• Special purpose facilities	100% to vehicles using special facilities by actual use data or by VMT
	• All other maintenance	100% to all vehicles by VMT

5. Overhead is assigned to all vehicle classes in proportion to the sum of the variable (service plus basic) costs of each class.

6. Cost splits in percent between environmental and weight-related portions were 22.6/77.4 for interstate, 34.0/66.0 for primary, and 46.9/54.1 for secondary highways.

7. Cost splits in percent between basic and truck-occasioned costs were 60.0/40.0 for interstate, 77.8/22.2 for primary, and 100.0/0.0 for secondary highways.

to climate only will have to be determined on the basis of judgment and experience. These amounts may be expected to vary from region to region within the state. A current study at Purdue University is expected to provide some insight into the effect of weather on routine maintenance costs [29].

For the purpose of allocating roadway maintenance costs due to traffic and its interaction with weather, a procedure has been developed in the present study, as discussed later is this section.

In the case of shoulder construction, use of capacity related cost allocators is justified; however, they may not be appropriate for the allocation of shoulder maintenance costs, because shoulder damages are more of a function of weather and traffic. The weather affects shoulder conditions more severely than pavements. Once constructed, functions of highway shoulders are to hold roadway pavement in place and strengthen it. Obviously the heavier trucks would cause more distress than the lighter vehicles. It is recommended, therefore, that the traffic-related component of shoulder maintenance costs be allocated in proportion to the costs assigned to vehicles for pavement maintenance. In this approach, assumption is made that the probability of using shoulders for emergency stops is equal for all vehicle classes.

All other maintenance costs, except bridge maintenance costs, are to be allocated as common costs to all vehicle classes because these costs cannot be directly related to the variation in highway use by different vehicle classes.

There are seven items under bridge maintenance, of which bridge maintenance contract work (Activity 247) can be judged partly to be the result of the interaction of traffic and weather. Consequently, this part of the maintenance cost can be allocated using the approach proposed for pavement

related maintenance costs. All other bridge maintenance costs can be considered to be common costs.

Some of the activities in the "Other" category include operational overhead such as supervision and equipment repair and maintenance and therefore these operational overhead costs will be grouped with administrative overhead. Administrative and operational overhead costs will be allocated to all vehicle classes in proportion to the sum of direct maintenance costs. These costs are first assigned percentwise to the three maintenance costs groups, then, allocated to vehicle classes by the cost allocator(s) of each cost group.

Data Base for Analysis

Routine maintenance costs for the state highway system are being estimated using the Routine Maintenance Records and Construction Reports. As for cost items, Routine Maintenance Records contain only labor, production units, types and quantities of materials used. Maintenance costs for labor and material will be computed by multiplying the labor and material units required for each activity by separately provided unit costs. Fuel consumption data are not found in Routine Maintenance Records, but are reported in lump sum for all maintenance works for each fiscal year. To distribute fuel costs to each activity, results of a previous study [28] concerning the fuel consumption rates of routine maintenance activities will be used. Routine maintenance activities that have been done by contract are found in Construction Reports file.

Procedure for Allocating Pavement Routine Maintenance Costs

The procedure for allocating pavement routine maintenance costs pursues

the same concept adopted for allocating pavement rehabilitation costs. The maintenance expenditure items included in the computation of routine maintenance costs are shown in Table 11.

As explained earlier in the section on allocation of pavement rehabilitation costs, an actual field performance curve of a given pavement would lie between the no-loss line and the zero-maintenance curve. The higher the level of routine maintenance performed, the closer is the field performance curve to the no-loss line.

In Appendix B, a technique is described which enables the zero-maintenance curve to be derived by considering pavement performance curves and their associated routine maintenance expenditure expressed in terms of average annual routine maintenance expenditure per lane-mile. Also presented in Appendix B is a proportionality rule by means of which the respective responsibility proportions of load-related and non-load-related effects of pavement damage can be computed.

Since the effects of non-load-related factors may be different for different regions (northern and southern Indiana), and pavement types (overlay, rigid and flexible pavements), maintenance expenditure data are being divided into six region-pavement type groups. In addition, six highway classes are being used in the present study and each with a different vehicle composition. This means that 36 routine maintenance expenditure subgroups in total need to be analysed in the cost-responsibility factor computation.

Table 11. Routine Maintenance Activities

IDOH Code No.	Activity Name
201	Shallow patching
202	Deep patching
203	Premix leveling
204	Full width shoulder seal
205	Seal coating
206	Seal longitudinal cracks and joints
207	Sealing cracks
209	Cutting relief joints
219	Others

ALLOCATION OF OTHER COSTS

Other costs include special vehicle services such as highway patrol and enforcement. These costs, at state and local levels, will be identified and allocated as common costs. Similarly, costs associated with general administration and overhead will also be treated as common costs and distributed in proportion to vehicle miles by vehicle class.

PROCEDURE FOR TRAFFIC DATA COLLECTION

One of the most critical data items necessary for a cost allocation study is information on number of vehicle miles travelled for each type of vehicles on each of the highway classifications. In addition, traffic data must also include the estimation of the number of axle miles travelled by axle weight, vehicle type and highway class. In the present study, a detailed vehicle count survey was undertaken to estimate vehicle miles of travel. Combining these estimates with the data from the IDOH Truck Weight Study, information on vehicle weight is being compiled.

Vehicle Count

The study team conducted a vehicle classification field survey at about 60 randomly selected sites throughout Indiana during the summer of 1983. The resulting data are being converted to represent an average day of the year with factors developed from the FHWA report "Vehicle Classification Case Study" performed for the HPMS [19]. A description of the procedures employed follows.

To obtain valid estimates of the travel by the various vehicle types on Indiana highways, it was necessary to perform classification counts at many randomly located sites. Random selection was used because of the following reasons:

1. Random selection guarantees that any resulting calculations will not be biased, as could happen if study locations were picked by hand. Random selection will insure that the selection is not biased toward certain regions of the state or toward more heavily travelled

highways.

2. Random selection allows the estimate of the accuracy of the results using the techniques of probability. It is impossible to estimate the accuracy from hand picked locations.

The basis for selecting a section of road was its length. This made subsequent VMT calculations easier because the VMT on a section of road with uniform flow is the product of the flow at a point and the section's length.

Rather than selecting from all the roads in Indiana, the roads selected were form the state's HPMS sample. These roads had already been picked with the probability of selection proportional to their length, and the locations were documented and marked on maps. The major problem was that the HPMS sample had been stratified by FHWA functional classification, ADT and, in the case of urban highways, the urban area in which the highway section is located. We wanted to stratify only by the highway classification scheme proposed for use in the present study. We were able to remove the stratifications based on ADT and urban area (as described below), but the conversion from FHWA functional classes to the adopted highway classes was more difficult.

Selection of Sampling Sites

Within each stratification of the HPMS sites, we had the total actual mileage in the stratification, total mileage of the HPMS sample

sections, and the identification of the sample sections. We might have had, say, 5 stratifications of the HPMS sample that we wanted to combine into 1 for our selection process.

We imagined lining up the actual mileage from each of the 5 stratifications on a single line. We then picked a milepost at random from along this line to be sampled. This milepost was a certain fraction of the distance from the start of the mileage for the stratification in which it fell. The HPMS samples for that stratification were also lined up, and the corresponding section actually selected was the one that contained the milepost that was the same fraction of distance along the line of sample HPMS sections.

This procedure was repeated until we had 10 sections for each FHWA functional classification, except local roads. When the time came to actually monitor the sites, we did not actually monitor all 10 sites, as discussed below.

The sites sampled according to the HPMS classification were ultimately grouped in terms of the highway classification used in the present study. This was done by identifying the location of each of the sites and matching the HPMS based sites with the study classification based sites. The resulting distribution of sites provided an adequate sample size to represent the volume in terms of the highway classification used in the study.

The number of sites counted within each study class is presented in Table 12. The variable number of sites in each study class is due to the fact that the present study classifies highway differently than the HPMS classification scheme and because 10 sites were selected from most of the HPMS classes.

The number of sites within each HPMS class is also presented in Table 12. Only two rural interstate sites were selected because the state already has much information on these highways. Also, the percentage of vehicles within each vehicle type on rural interstates is quite stable, according to an examination of sites observed by the IDOH in 1981. The small number of sites in the lower functional categories is due to the lack of traffic on these roads and the difficulty in finding suitable sites.

Field Data Collection Procedures

Most of the data collection was performed by a team of 4 data collectors and a team leader. Partway into the data collection, a program became available for the Streeter-Amet Traficomp that accurately classifies vehicles according to axle number and spacing. The procedures using both manual and machine counts follow.

Manual Data Collection

The team leader visited the road section to be sampled and picked an

Table 12. Number of Traffic Count Sites

Study Class	Number of Sites
Interstate Urban	9
Interstate Rural	2
State Routes Primary	22
State Routes Secondary	7
County Roads	4
City Streets	8

HPMS Class	Number of Sites
Rural Interstate	2
Rural Other Principal Arterials	8
Rural Minor Arterials	6
Rural Major Collectors	2
Rural Minor Collectors	3
Urban Interstate	9
Urban Freeways and Expressways	8
Urban Other Principal Arterials	9
Urban Minor Arterials	4
Urban Collectors	1

exact observation point within the section. Other observers followed and, in 4 shifts of 6 hours each, observed traffic in both directions as it passed their observation point. Counter boards were used to keep track of all except the rarest types of vehicles, for which a separate piece of paper was used. Each hour, the counts for the various vehicle types were recorded on sheets similar to the ones the State uses for its truck weight study.

Twenty-four hours of data were collected at each site. The method of adjusting the raw values to yearly values is described below. The information from the data sheets was transcribed into computer files for analysis.

Machine Data Collection

Streeter-Amet Traficomp recorders were used on 11 2-lane roads late in the data collection period. The program used was the just-released "Type-14-60" tape, part no. 2137020B, which classifies vehicles into 14 classes based on axle number and distance between axles. There was some initial doubt about an earlier version of the program, but field tests of this latest program proved it to be quite accurate.

Two road tubes were stretched across each lane of the 2-lane road, so that each direction could be collected separately (The program is directional). The recorders were left out for at least 24 hours. The data were then transferred directly to the Purdue Civil Engineering Computer for analysis.

Data Reduction and Analysis

For each road section, we now have raw figures for the number of vehicles of each type that use that road on a summer weekday. The collected data had to be adjusted to account for daily and seasonal variations. For this, we used the Vehicle Classification Case Study. In several other states, data were collected year-round and on both weekdays and weekends. From these data we developed factors that reflected the change in travel of each type of vehicle on roads within each HPMS functional class. We are using these factors to adjust our observed data to estimate the counts we would have seen if we had actually observed the sites year-round.

Estimation of Various Measures of Vehicle Use

On the basis of the traffic count data and other available information, several types of necessary traffic related values can be estimated. Procedures for source of these estimations are listed below.

Vehicle-Miles Travelled Per Year

Since road sections were selected with probability of selection proportional to the section's length, the number of vehicle-miles traveled for a given vehicle type on roads of a certain functional class is simply the arithmetic average of the number of vehicles counted on the sample sites in that functional class times the total number of actual miles in the class (known from the HPMS) times 365 days a year.

Axle-Miles Traveled Per Year

The number of axles on a vehicle in a given vehicle class is known, so the number of axle-miles for a given vehicle class is simply the number of VMT times the number of axles on the vehicle.

Axle-Miles by Axle-Weight Per Year

Every two years, IDOH conducts a Truck Weight Survey. As part of this survey, data on truck weights by truck type are collected at the permanent weigh stations and at several temporary locations. The data file includes records of the type, weight, registration and other pertinent information for every truck weighed as a part of the truck weight study. The data for 1981 have already been analyzed to find the axle-weight distributions for each truck type on highways in each highway class. The analysis is underway for the 1983 data.

The axle-weight distributions will be combined with the axle-miles travelled calculated above to find the axle-miles by axle-weight from each vehicle type on highways in each class.

REVENUE ATTRIBUTION

After cost responsibilities are identified it is necessary to examine revenue payment by vehicle class to provide a base for comparison. The apportionment is to be done of appropriate revenues paid by Indiana highway users to state, federal and local governments. In particular, the user revenues to be considered are those which went to support highway construction, operation and maintenance activities in Indiana.

State Highway Revenues

The Indiana system of highway user taxation consists primarily of the motor fuel taxes, registration fees, motor carrier fees, and vehicle operator's fees. In addition, miscellaneous revenues in the nature of fines and charges are collected and deposited in the Motor Vehicle Highway Account (MVHA). However, only that part of the total user revenues that can be associated with the highway construction, operation and maintenance activities will be apportioned. In Figure 3 is presented the current organization of the MVHA. The majority of highway revenues in Indiana is gathered in MVHA. Fuel taxes and registration fees are the main sources of revenues for the MVHA. The other highway related fund is the Highway Road and Street Fund (Primary Fund). A part of the motor fuel tax is gathered in the Primary Fund for use in two separate accounts, the Primary Highway System Special Account and the Local Road and Street Account. In Figure 4 is presented the procedure to distribute motor fuel taxes in Indiana.

Figure 3. Organization of the Motor Vehicle Highway Account (MVHA)

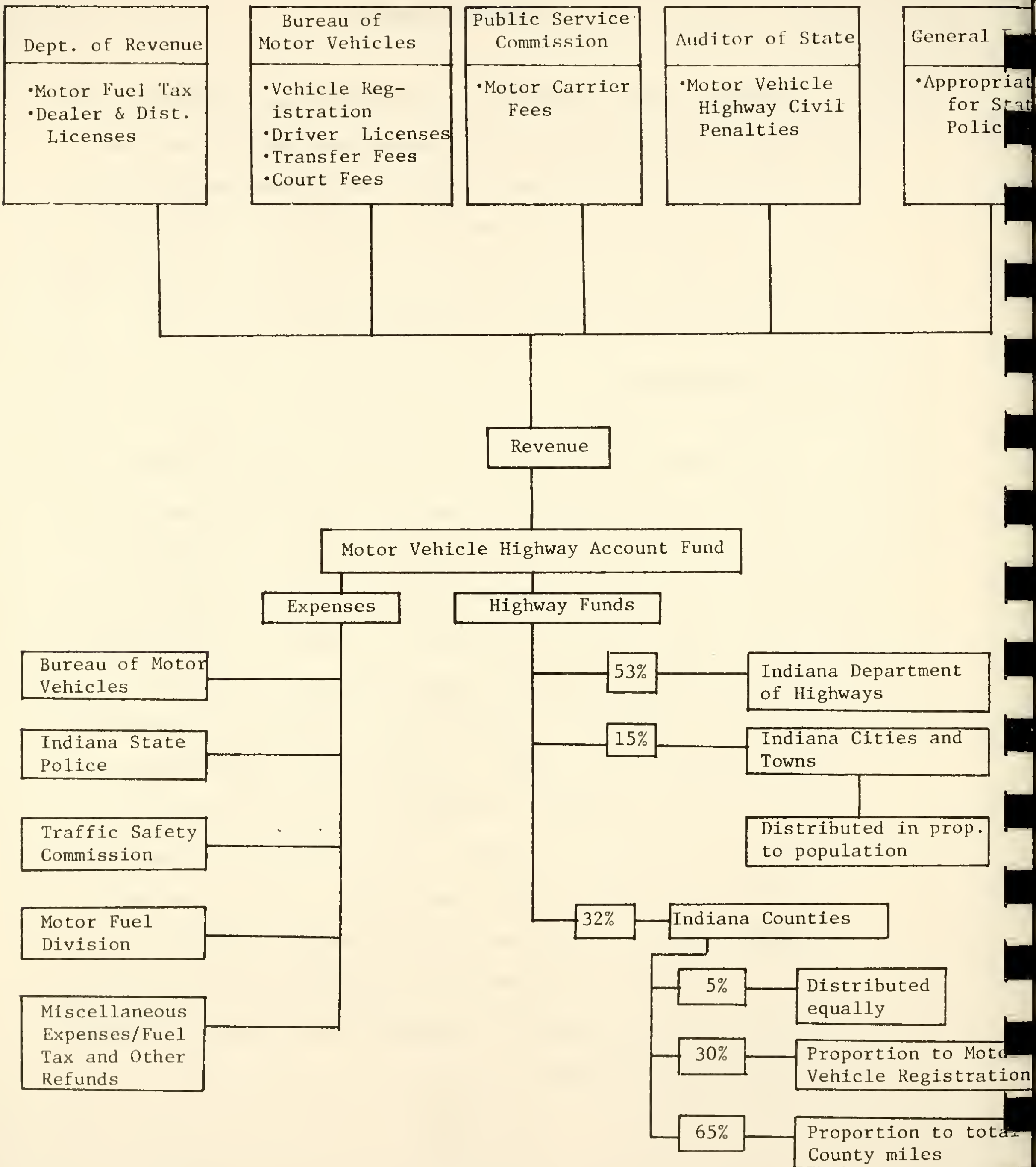
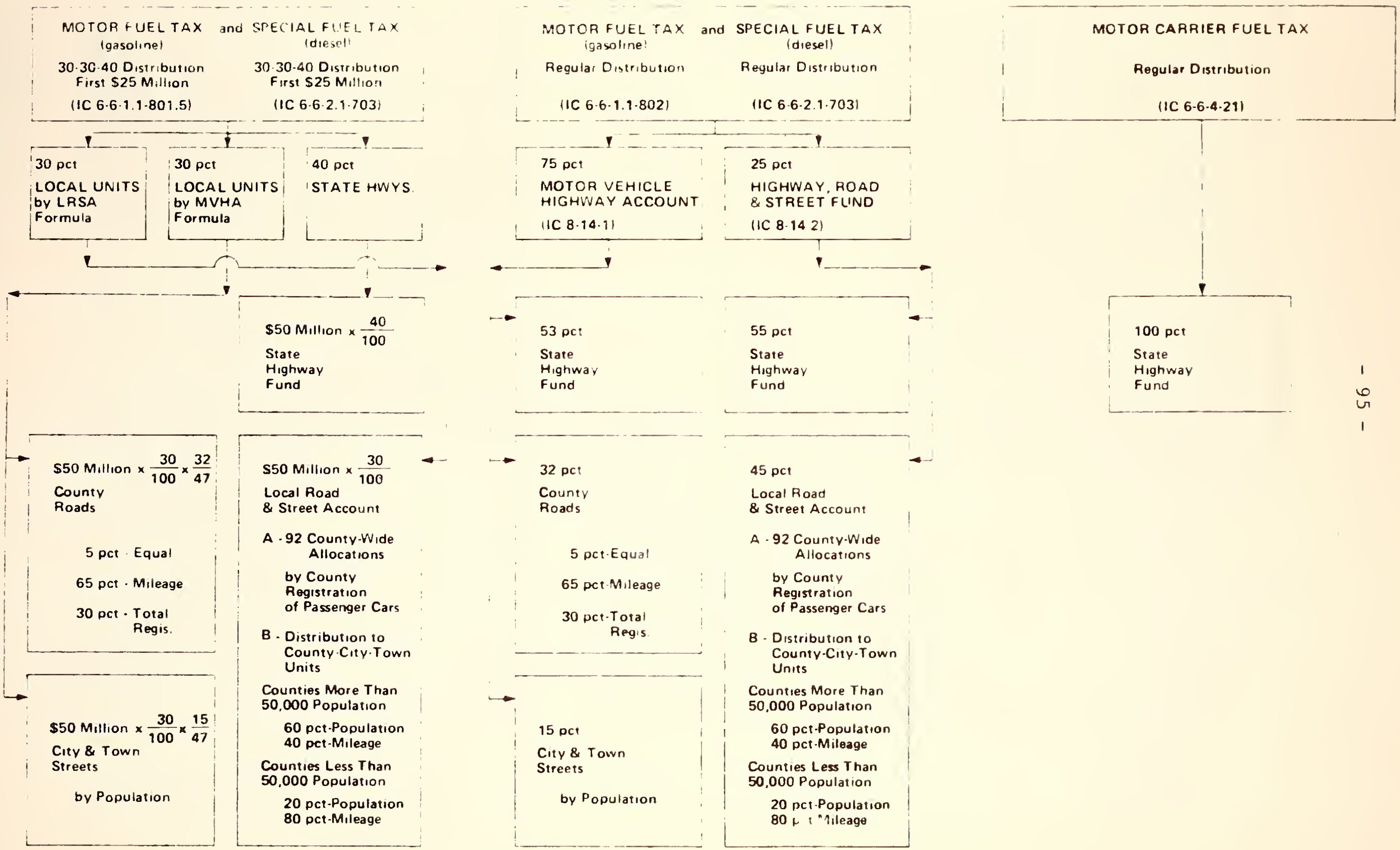


Figure 4. Distribution of Motor Fuel Tax Revenues



In Table 13 is presented a report on fiscal activity in MVHA during 1978-82 and in Table 14 is presented revenues for Indiana Department of Highways during 1976-82.

The federal funds available to Indiana are generated through Federal Trust Fund consisting of revenues from motor fuel tax, sales tax, use tax, parts and accessories tax, tires and tubes tax and tax on lubricating oil. Total FY 1982 contributions generated by these charges from Indiana's highway users were 185.7 million. It should be noted that only that portion of the federal revenues that was received by Indiana will be considered in revenue analysis.

In addition to state and federal charges, a small amount of user fees and taxes is collected by some local governments in the form of local option taxes.

Methodology for Revenue Attribution

Each of the state highway user charges needs to be examined separately to attribute the shares of revenues to vehicle classes.

Fuel Tax Revenues

Fuel taxes are dependent upon fuel consumption which in turn is related to vehicle-miles of travel and vehicle fuel efficiency. The VMT values by vehicle class for 1983 will be available from the traffic count data. Fuel efficiency estimates by vehicle class for the same year will be generated by using the fuel efficiency model developed in an earlier study performed for the IDOH [22]. The figures from the FHWA Cost

Table 13. Report of Fiscal Activity in Motor Vehicle Highway Account

	F.Y. 1978	F.Y. 1979	F.Y. 1980	F.Y. 1981	F.Y. 1982
REVENUES					
MOTOR FUEL TAX	$200,490,189	$207,539,086	$199,101,399	$193,578,831	$187,254,774
MOTOR FUEL TAX REFUNDS	(2,774,369)	(2,406,085)	(2,059,950)	(1,936,793)	(2,585,001)
VEHICLE LICENSE FEES	70,532,346	73,504,986	73,477,481	84,682,995	88,669,989
GEN. FUND TRANSFER FOR STATE POLICE	20,531,041	23,202,959	25,470,607	27,670,651	27,271,876
FEDERAL REIMBURSEMENTS	3,310,824	3,941,964	4,980,282	4,730,730	2,214,389
VEHICLE INSPECTION FEES	1,847,301	1,819,232	888,198	(1,081)	-0-
DRIVER COURT FEES	1,049,613	1,169,872	1,280,599	1,190,140	1,515,540
REINSTATEMENT FEES	50,820	84,910	88,500	114,535	129,935
EXCESS P.S.C.I. FUNDS	427,155	171,232	-0-	45,126	382,521
MISCELLANEOUS RECEIPTS	1,524,995	1,334,832	1,900,285	1,822,776	1,956,072
TOTAL REVENUES	$296,989,915	$310,362,988	$305,127,401	$311,897,910	$306,810,095
DISBURSEMENTS PRIOR TO DISTRIBUTION					
BUREAU OF MOTOR VEHICLES:					
OPERATING EXPENSES	$ 13,177,518	$ 15,967,670	$ 17,073,875	$ 15,108,827	$ 16,305,406
LICENSE PLATE MATERIALS	938,418	2,906,621	3,231,955	3,215,478	2,061,208
TOTAL BMV	$ 14,115,936	$ 18,874,291	$ 20,305,830	$ 18,324,305	$ 18,366,614
STATE POLICE:					
OPERATING EXPENSES	$ 36,698,230	$ 38,135,729	$ 45,343,193	$ 48,406,353	$ 46,858,948
PENSION & BENEFIT FUNDS	5,889,891	6,691,852	6,231,704	8,077,804	8,240,958
ENFORCEMENT AID	43,413	50,000	69,806	100,000	121,500
TOTAL STATE POLICE	$ 42,631,534	$ 44,877,581	$ 51,644,703	$ 56,584,157	$ 55,221,406
TRAFFIC SAFETY COMMISSION:					
OPERATING EXPENSE	$ 4,006,000	$ 5,233,367	$ 5,099,508	$ 5,572,783	$ 5,246,189
SCHOOL SAFETY	26,887	68,995	83,751	93,320	134,010
TOTAL TRAFFIC SAFETY	$ 4,032,887	$ 5,302,362	$ 5,183,259	$ 5,666,103	$ 5,380,199
MOTOR FUEL DIVISION - DEPT. OF REVENUE	$ 671,102	$ 703,983	$ 710,260	$ 966,222	$ 739,377
MISCELLANEOUS EXPENSES & ADJUSTMENTS	$ 194,066	$ (634,624)	$ 1,181,184	$ 30,891	$ 686,935
TOTAL DISBURSEMENTS	$ 61,645,525	$ 69,123,593	$ 79,025,236	$ 81,571,678	$ 80,394,531
DISTRIBUTION					
INDIANA DEPARTMENT OF HIGHWAYS	$124,910,139	$128,217,591	$120,432,166	$122,072,903	$120,000,249
COUNTIES	75,154,969	76,804,207	71,651,914	73,704,394	72,452,980
CITIES & TOWNS	35,279,282	36,217,597	34,018,085	34,548,935	33,962,335
TOTAL FUNDS DISTRIBUTED	$235,344,390	$241,239,395	$226,102,165	$230,326,232	$226,415,564
TOTAL DISBURSEMENTS & DISTRIBUTIONS	$296,989,915	$310,362,988	$305,127,401	$311,897,910	$306,810,095

Table 14. Revenues for Indiana Department of Highways (in Millions)*

Fiscal Year	Motor Vehicle Dist.	Force Acct. Reimburse. & Misc.	Dedicated Primary Account	Gen. Fund Transfer to Highway	Sub-Total	Federal Contractual Reimburse.	Federal & Local LPA Receipts	Sub-Total	Grand Total
1976	112.863	18.802	47.163	23.066	201.894	119.734	5.719	125.453	327.347
1977	122.282	22.266	49.317	10.600	204.465	96.894	4.987	101.881	306.346
1978	124.910	18.416	49.258	5.667	198.251	74.748	8.309	83.057	281.308
1979	128.218	16.303	51.544	28.333	224.398	125.031	14.396	139.427	363.825
1980	120.432	15.739	49.082	40.000	225.253	124.150	14.156	138.306	363.559
1981	122.073	19.213	48.178	20.000	209.464	165.321	14.840	180.161	389.625
1982	138.000**	17.976	50.208	-0-	206.184	141.883	13.265	155.148	361.332

* Does not include revenues for the Distressed Road Fund or Toll Bridge.

** Includes Special Motor Fuel Tax Distribution.

Allocation Study [8] will also be considered in developing the fuel efficiency rates. To compute fuel consumption, annual VMT for a specific vehicle class will be divided by its fuel efficiency value. Gallons of fuel consumed will then be multiplied by the appropriate tax level. In computing fuel tax revenues, consideration will be given to the difference in tax requirements for gasoline, diesel, and other fuels such as gasohol and butane. Appropriate adjustments would be necessary to account for non-highway uses of motor fuels. In addition, proper considerations should be given to the fact that the fuel consumed in publicly-owned vehicles is tax exempted, although these vehicles are users of highway services.

By estimating the appropriate annual vehicle-miles of travel and fuel efficiency rates for 1985-86, the attribution of fuel tax revenues for the study year can be accomplished.

Registration Fees

Vehicle license fees are levied on vehicles registered in Indiana. A flat registration fee is charged to private automobiles, while the fee schedules for commercial vehicles are graduated by weight. Detailed data on license fee collections by vehicle class are available from the Department of Motor Vehicles. The primary attribution procedure for these revenues will involve aggregating weight groups into the vehicle classes used in the present study.

Federal Revenues

In order to attribute Federal excise taxes among Indiana highway users, the method developed by the FHWA for deriving the federal user charges contributed by vehicles classes will be followed.

Miscellaneous Revenues

All other fees and charges levied on the operation and ownership of motor vehicles in Indiana will be apportioned directly among various vehicle classes according to the type of these revenues, if applicable.

Other Considerations

A significant part of the commercial vehicles on Indiana highways are from other states. The fees and taxes paid by these vehicles are different and much lower than the Indiana based commercial vehicles. For the purpose of cost allocation as well as for revenue attribution, appropriate adjustments should therefore be made to account for the out-of-state commercial vehicles using Indiana highways.

CONCLUSIONS

This report has presented guidelines that are being used in the present Indiana highway cost allocation study. On the basis of a detailed review of the existing cost-allocation studies, an integrated set of methodologies has been developed for application in Indiana. A new approach has been proposed for allocation of costs for new highway construction, highway rehabilitation and routine maintenance. This approach is consistent with the state-of-the-art pavement design and maintenance procedures and at the same time the proposed procedures would achieve a higher degree of equity in establishing cost responsibilities among highway users than what is provided by the existing cost-allocation methodologies.

Highway cost allocation and subsequent analysis of revenue attribution should not be considered as a one-time exercise. Instead, it should be recognized as a part of a continuing process of pricing and financing highway services in Indiana. A periodic updating of the cost responsibility and revenue attribution factors is essential in order to keep abreast with the changing traffic distributions, changing expenditure patterns, changing program emphasis, and changing technology. In addition, the procedure and methodology of the highway cost allocation process itself change with time, as new information on such key elements as relationships between traffic load, weather, and pavement and structure damage is generated.

APPENDIX A

Computational Algorithm of the Thickness Incremental Method

Inputs to the algorithm include (a) cost information, (b) pavement data, (c) traffic composition, vehicle axle configuration and axle-weight data. For rigid pavement, cost can be assumed to be directly proportional to the slab thickness. For flexible pavement, separate costs for surface, base and subbase construction are needed.

The computation algorithm for cost-allocation involves the following steps:

1. Divide the pavement thickness in excess of a practical minimum into N equal increments. In the case of flexible pavement, each increment is composed of thickness of surface, base and subbase materials in the same proportions as are in the total 'excess' thickness to be allocated.

2. Calculate the cost for the minimum thickness and distribute to all vehicle classes on the basis of VMT.

3. Calculate the incremental thickness cost.

4. Add an increment to the minimum thickness, and compute ESAL for all vehicle classes (or vehicle types if desired) using AASHTO ESAL equations.

5. Compute the cost responsibility factor of each vehicle class (or vehicle types) as the following ratio:

$$F(i,j) = P(i) \times ESAL(i,j) \Big/ \sum_{r=1}^{M} \left[P(r) \times ESAL(r,j)\right] \qquad (A.6)$$

where,

F(i,j) = cost responsibility factor of vehicle class i for thickness increment j

P(i) = proportion of vehicle class i in traffic stream

ESAL(i,j) = ESAL of vehicle class i for thickness increment j

M = total number of vehicle classes

6. Allocate incremental thickness cost to each vehicle class as follows:

$$c(i,j) = F(i,j) \times Cd(j) \qquad (A.7)$$

where,

c(i,j) = cost allocated vehicle class i for thickness increment j

Cd(j) = incremental cost for thickness increment j

7. Repeat steps 5 and 6 for each new thickness increment until the full pavement thickness is reached.

8. Calculate the total allocated cost for vehicle class j by summing up its cost responsibility for all increments:

$$C(i) = Cm(i) + \sum_{j=1}^{N} c(i,j) \qquad (A.8)$$

where,

C(i) = total cost responsibility of vehicle class i

Cm(i) = cost responsibility of vehicle class i for the minimum thickness

N = total number of thickness increments

APPENDIX B

Determination of Cost-Responsibility Factors of Load-Related and Non-Load-Related Factors in Pavement Rehabilitation and Maintenance Cost Allocation

As discussed in the section on allocation procedure of pavement rehabilitation costs, pavement wear or damage may be represented by appropriate areas in a pavement performance (PSI vs. ΣESAL) plot. In Figure B.1, the shaded area $(A + B)_o$ between curves 3 and 4 represent the total pavement damage of a given stretch of pavement. Curve 3 is a hypothetical no-loss line and curve 4 is a hypothetical performance curve for the pavement concerned in a situation where no maintenance at all has been carried out.

Consider a stretch of pavement which is maintained by a particular highway agency with known technology, facilities, and manpower, and assume that the efficiency of the working crew remain the same for the period of analysis. Under these conditions it is reasonable to say that the expenditure spent on maintaining the pavement would be positively related to the level of routine maintenance performed. That is, in terms of constant dollars higher expenditure is likely to be associated with higher levels of maintenance. In Figure B.2, one would expect the expenditure level S_3 to be greater then S_2, S_2 greater then S_1, and so on.

Performance curves based on Indiana design equations vary with the following factors: type of pavement, region, terminal PSI, materials and traffic. Indiana material and regional factors estimated in an earlier

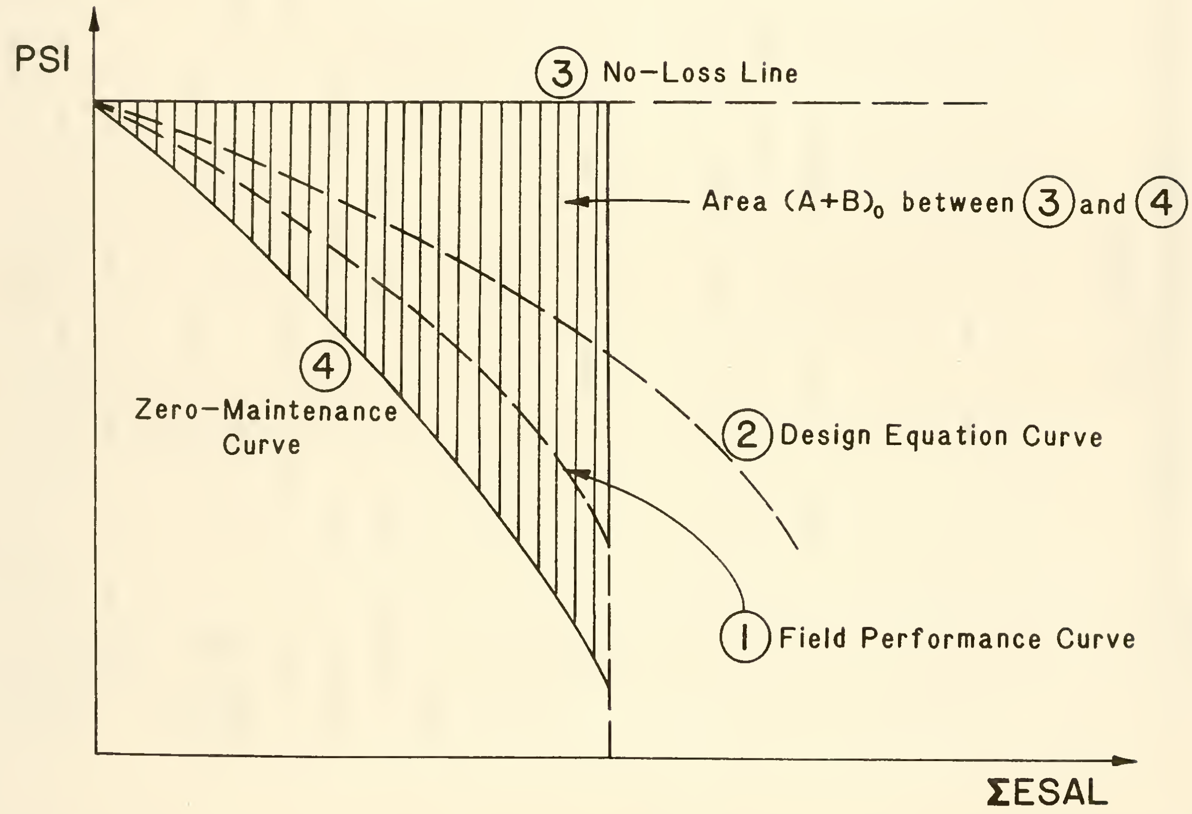


Figure B.1 Total Pavement Damage as Defined by Zero–Maintenance Pavement Performance Curve.

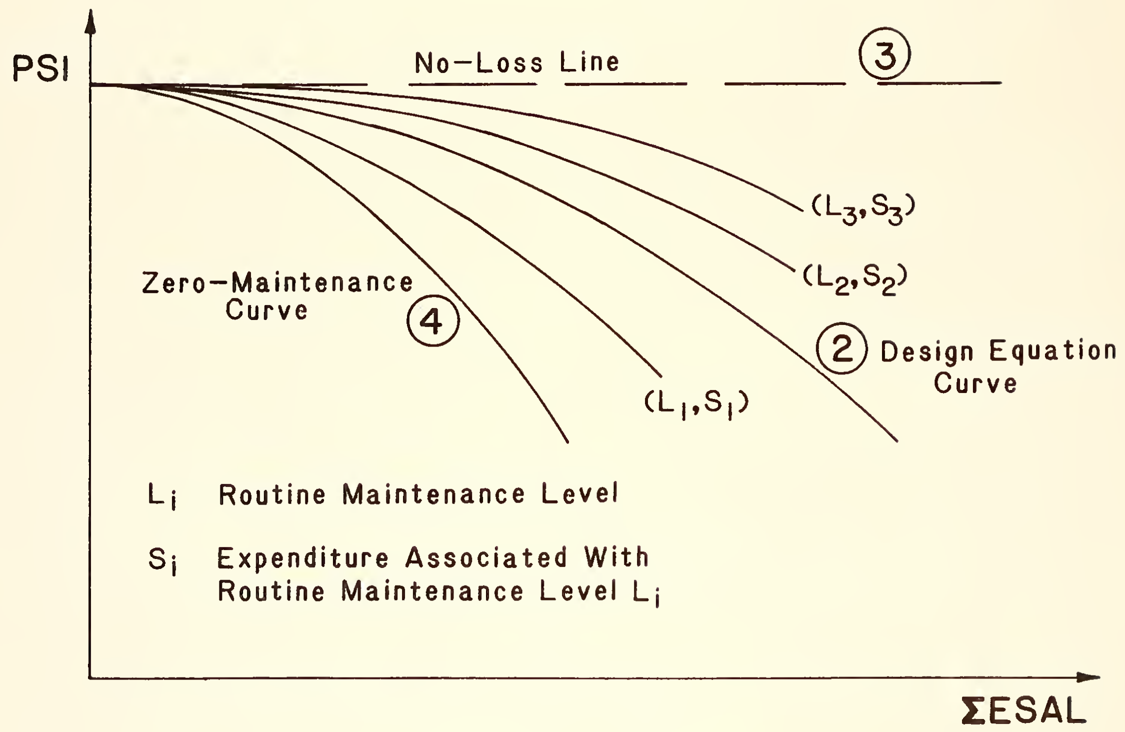


Figure B.2 Schematic Diagram Showing Pavement Performance Curves with their Associated Routine Expenditures.

work done at Purdue University [5] would be used for this purpose. Cost-allocation analyses would be performed by highway class and type of pavement. For each pavement section on which a rehabilitation has been performed during the study period, performance curves corresponding to Indiana design equations sand actual field performance would be developed.

The Road-Life Records of the Indiana Department of Highways contain the following information for each route of the State Highway system:

1. Pavement type
2. Pavement thickness
3. Pavement age since the time of major improvement
4. Layer material characteristics, and
5. Construction costs

Pavement roughness measurements on Indiana State Highways since 1979 are available from JHRP tapes at Purdue University. These roughness measurements can be related to PSI by using relationships established for Indiana in previous studies performed at Purdue University [23,24]. The relationships derived for different types of pavements are summarized in Table B.1.

For a given pavement, knowing a PSI value and the corresponding cumulative ESAL, a point on the actual performance curve of the pavement is obtained. This procedure may be repeated for other points of time at which data are available. Field performance curve of the pavement may then be plotted, and the area between this curve and the no-loss line, ie. area (A+B), may be computed.

Table B.1. Relationship Between Present Serviceability Index (PSI) and Roughness Number (RN)

Pavement	Relationship
Asphalt	PSI = 3.94 - 0.00072(RN)
Overlay	PSI = 4.37 - 0.00174(RN)
Jointed Reinforced Concrete (JRC)	PSI = 4.69 - 0.00141(RN)
Continuously Reinforced Concrete (CRC)	PSI = 4.40 - 0.00070(RN)
JRC & CRC (combined)	PSI = 4.58 - 0.00114(RN)

The annual routine maintenance cost per lane-mile of a pavement section is obtained by dividing its annual routine maintenance expenditures by its total lane-miles. The annual routine maintenance expenditures over the analysis period are considered to compute the average maintenance cost for the highway section under consideration.

Routine maintenance information is documented by highway section which is defined as the portion of a highway that lies within the boundaries of a county. Highway section was therefore chosen as the basic unit of analysis in the present study. When a pavement section contains more than one roughness measurement, a weighted average of area (A+B) is calculated using the lane-mile of each roughness measurement as the weighting factor.

For a stretch of pavement with more than one highway section, the zero-maintenance curve of the pavement was derived by plotting the areas (A+B) of these highway sections against their respective average annual routine maintenance expenditure per lane-mile. A least square line was then fitted to the data points. The intercept of this line with the (A+B) axis gives area $(A+B)_o$ of the zero-maintenance curve of the pavement under consideration.

The next step involves the computation of load-related and non-load-related responsibility factors using proportionality assumption. Figure B.3 assumes that the interaction effects is composed of two components, namely the load-related and non-load-related parts. Proportion a is equal to $\frac{A}{(A+B)_o}$ which could be computed for a given stretch of pavement with the procedure described in preceding paragraphs.

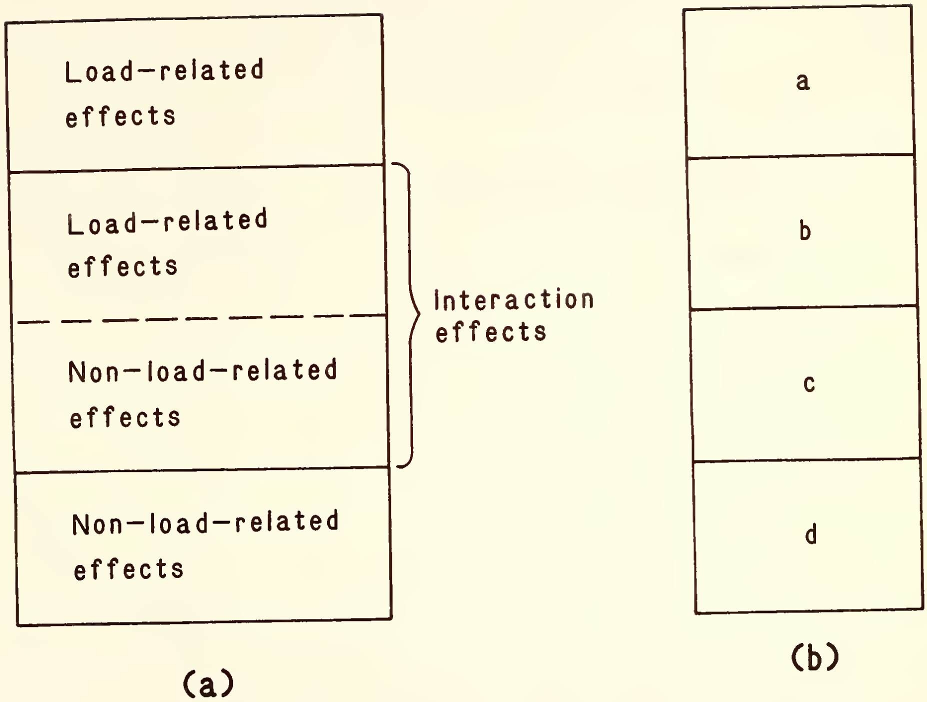


Figure B.3 Schematic Diagram Showing Load-related and Non-load-related Effects Responsible for Pavement Damage.

Knowing proportion a, it is possible to calculate proportions b, c and d by making the following proportionality assumption:

$$\frac{b}{b+c+d} = \frac{a}{a+b+c+d} \qquad (B.1)$$

$$\frac{c}{a+b+c} = \frac{d}{a+b+c+d} \qquad (B.2)$$

Equation (B.1) assumes that for a given 'pure' load-related effects (proportion a), the share of load-related effects in the remaining non-load-related and interaction effects is directly proportioned to the share of 'pure' load-related effects in the overall effects (a+b+c+d). Similarly, equation (B.2) assumes that for a given 'pure' non-load-related effects (proportion d), the share of non-load-related effects in the remaining load-related and interaction effects is directly proportioned to the share of the 'pure' non-load-related effects in the overall effects (a+b+c+d).

Solving for d using equations (B.1) and (B.2), it gives:

$$d = 1 - \sqrt{1-(1-a)^2} \qquad (B.3)$$

Proportions b and c may then be determined from solving equations (B.1) and (B.2). the total responsibility proportion of load-related effects is given by (a+b) and the total responsibility proportion of non-load-related effects by (c+d).

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